MEASURING A SUBSYSTEM-SYSTEM RELATIONSHIP AND TRADEOFFS IN AFGHANISTAN: A COUNTRY CASE STUDY EXAMINING THE ROLE OF IMMUNIZATION IN HEALTH SYSTEM PERFORMANCE

by
Holly B. Schuh

A dissertation submitted to Johns Hopkins University in conformity with the requirements for the degree of Doctor of Philosophy.

Baltimore, Maryland
April 2017

© 2017 Holly B. Schuh
All Rights Reserved

Abstract

Problem statement. Health systems are complex and adaptive, and their behavior can be misunderstood if not considering their complexity and dynamism. This study examines the relationship between health system *readiness to deliver routine immunization services* and *immunization performance outcomes* as well as *non-immunization performance outcomes*.

Methods. Paper 1 presents an ecological study examining the association between *system readiness to deliver routine immunization services* and *immunization performance* using generalized linear models. Paper 2 presents a mapping exercise of the immunization systems using an iterative, causal loop diagram (CLD) building process to explore pathways through which *immunization readiness* may affect *immunization and non-immunization outcomes* in Afghanistan's health system. Paper 3 presents a system confirmatory exercise using SD modeling to examine the anticipated year-to-year impact of system readiness components on immunization and non-immunization service coverage.

Results. Average vaccine stock readiness in provinces was associated with the largest change in immunization coverage among all readiness factors (10-percentage-point increase in scores associated with 3.92 to 5.19-percentage-point increase in immunization coverage). Basic laboratory capacity scores were also associated with change in immunization coverage (10-percentage-point increase in scores associated with 1.51 to 1.65-percentage-point increase in immunization coverage). Demand-side factors like household wealth and mothers' health behaviors were also significant predictors of immunization performance. Four CLDs were created to collectively represent the

Afghanistan routine immunization system. *Demand*-, *cold chain*-, and *health worker and health care recipient*- pathways leading to immunization and non-immunization outcomes were most discussed by experts. The year-to-year impact of health worker capacity on antenatal care (ANC) coverage was a -1.65-percentage-point change. No components statistically significantly affected immunization coverage. The overall year-to-year change in ANC and immunization coverage were 7.64 and 1.77-percentage-point increases, respectively.

Conclusion. Efforts to understand the complexity of logistics systems could support vaccine availability. Mechanistically, the role of laboratories/surveillance in immunization performance should be explored. Resiliency of system readiness is likely time-step sensitive and unpredictable in environments like Afghanistan. Limited data availability on routine immunization system actors (demand-side and supply-side) and their behaviors as well as measures of demand affect the ability to understand many of the mechanisms underlying routine immunization system behavior.

Thesis readers:

Dr. Takeru Igusa Professor and Committee Chair	Arts & Sciences – Civil Engineering
Dr. Maria Merritt Associate Professor and Thesis Advisor	International Health
Dr. David Peters Professor	International Health
Dr. David Dowdy Associate Professor	Epidemiology

Alternate thesis readers:

Dr. Bruce Lee Associate Professor	International Health
Dr. Nancy Kass Professor	Health Policy and Management

Intended to be blank.

Acknowledgements

To my thesis and academic advisor, Dr. Maria Merritt: Your thoughtfulness as an educator and mentor have been so evident during my time in the health systems program. We need more individuals like you who care about the educational experience of students and who take the responsibility of mentorship as a privilege. I will remain grateful to you for the time and wisdom you shared with me during my doctoral experience.

To the members of my final reading committee for the final thesis defense: Drs. David Peters, Takeru Igusa, and David Dowdy, I appreciate the time that you gave to provide thorough comments and review of my work. It made the final exam that much more of a learning (and enjoyable) experience. Dr. Peters, thank you for the opportunity to work in the country of Afghanistan, for your mentorship in the field of health systems research, and for your letters of support for various scholarship activities. Dr. Igusa, thank you for your patience and guidance through the systems modeling process. Your personal time that was dedicated to building models together has enriched my learning experience and this thesis research. Dr. Dowdy, special thanks for serving as a member on the final committee of readers. Though I have not worked with you during my time here at the JHSPH, your willingness to not only review my work but also your extra efforts to understand me and my experience as a doctoral student are noted and much appreciated.

To Drs. Bruce Lee, Daniel Salmon, Kunle Alonge, and Nancy Kass: thank you for serving as members or alternates for the departmental thesis committee, the final readers committee, and the committees for preliminary oral exams. Dr. Lee, thank you for the extra reviews of manuscripts. Dr. Salmon, thank you for the extra meetings regarding career opportunities and guidance. Dr. Alonge, thank you for the extra guidance on methodologies and approaches to the research questions. Drs. Kass and Salmon, thank you for your willingness to serve as alternates for the committee of final readers with such short notice.

To Julia Zhang, PhD candidate in the health systems program: thank you for your consultation on biostatistics methods and your review of the first paper in this thesis. Your professionalism, knowledge, and skills are highly noted, and I'm privileged to call you colleague and friend. Good luck with your upcoming defense.

To the Loma Linda University School of Public Health: Many of your faculty and staff have been of tremendous support during my studies away from Loma Linda. Dr. Juan Carlos Belliard, Molly Dougherty, Dr. Jayakaran Job, Dr. Ronald Mataya, Dr. Karl McCleary, and Dr. Susanne Montgomery, thank you for the many conversations, colleagueship, mentorship, and friendship. To the University, thank you for the financial support that I know was a great amount for a small school.

To my colleagues from the former Johns Hopkins University country office in Kabul, Afghanistan: thank you for the many memories, friendship, and support during my stay in Kabul. You helped to make it a rich personal and professional development experience. Besyar tashakor for making it feel like home during my seven-month stay.

To Dr. Ruth Karron, the PAVE scholars program, the Department of Immunisation, Vaccines, and Biologicals (IVB) at the World Health Organization headquarters, and Drs. Kamel Senouci and Thomas Cherian: thank you for the training opportunity and the additional professional experience. The experience bolstered my faith in public health and people who care about the greater good. The opportunity to work with the IVB department is irreplaceable for my career and life experiences.

To Drs. Sachi Ozawa, Anbrasi Edward, Shivam Gupta, and Noni MacDonald: each of you has taken the time to mentor me during the past five years, and I am truly grateful. These are the investments that are difficult to measure, but they have brought me through moments of personal and professional development. I do hope our paths cross often as I continue to grow as a young investigator.

To Karla McCarthy, Cristina Salazar, and Elliot Rosen at the JHSPH: thank you for your additional support and advocacy during my time here as a student. It is clear that each of you cares about students, and you live up to this distinction in your professional service to the International Health department.

To my family: Mom, Dad, and Aileen, you each are so important to me. Your support and patience during this endurance race have not gone unnoticed. I admire each of you for a different reason, and my life lessons have always stemmed back to “home”. Love you.

To my friends and “family” in: Baltimore, MD, USA; Geneva, Switzerland; Kabul, Afghanistan; Loma Linda, CA, USA; and Rochester, MN, USA. I do not want to make the mistake of listing everyone and then forgetting someone! I hope you know who you are and if I did not express how much your companionship during this journey has meant to me, I want to express it here. Thank you for the walks, the laughter, the tears, the prayers, and the memories as each of us pursues our own individual dreams. Accompaniment has made the journey that much more enjoyable, even through very difficult times and circumstances. Thank you for helping me to become a better person.

To my God, Savior, and Friend: I owe everything to you. Your faithfulness, wisdom, grace, and mercy are incomprehensible, and as Paul said in the book of Acts, “I consider my life worth nothing to me…” except that I might “…testify to the good news of Your grace”.

Table of Contents

List of Tables

List of Figures

List of Abbreviations

AEFI – adverse events following immunizations
AFP – Acute Flaccid Paralysis
AHS – Afghanistan National Household Survey
ANC – Antenatal Care
ARI – Acute respiratory infection
BCG – Bacillus Calmette-Guérin
BHC – Basic Health Centers (part of Afghan health system)
BMGF – Bill and Melinda Gates Foundation
BPHS – Basic Package of Health Services
BSC – Balanced Score Card
CHC – Comprehensive Health Centers (part of Afghan health system)
CHW - Community Health Workers
CLD – Causal Loop Diagram
cMYP – comprehensive multi-year planning (for immunization)
CSO – Civil Society Organization
DH – District Hospitals (part of Afghan health system)
DTP3 – Diphtheria-Tetanus-Pertussis, third vaccine dose
EPHS – Essential Package of Hospital Services
EPI – Expanded Programme on Immunisation
GLM – Generalized Linear Models
GHI – Global Health Initiative
GNI – Gross National Income
Hib – Haemophilus influenza type B
HMIS – Health Management Information System
HP – Health Post (part of Afghan health system)
ICRC – International Committee of the Red Cross
IIHMR – Indian Institute of Health Management Research
IRB – Institutional Review Board
JHSPH – Johns Hopkins Bloomberg School of Public Health
JSI – John Snow International
MDG – Millennium Development Goal
Measles1 – first dose of measles vaccine
MHT – Mobile Health Teams (part of Afghan health system)
MNT – Maternal neonatal tetanus
MoPH – Ministry of Public Health
NGO – Non-Governmental Organization
Obgyn – physicians specializing in obstetrics and gynecology
PCA – Principal component analysis
Pentavalent3 – third dose of the DTP, hepatitis B, and Haemophilus influenza type B vaccines
PEPFAR – U.S. President's Emergency Plan for AIDS Relief
Polio3 – third dose of polio vaccine
RI – Routine Immunization
RBF – Results Based Financing

SAGE – Strategic Advisory Group of Experts on Immunisation
SBA – Skilled Birth Attendance
SC – Health Sub Centers (part of Afghan health system)
SD – System Dynamics
SDG – Sustainability Development Goals
SBA – Skilled birth attendance
TB - Tuberculosis
UCI – Universal Childhood Immunisation
UNICEF – United Nations Children's Fund
USAID – United States Agency for International Development
VIF – Variance Inflation Factor
WHO – World Health Organization

Intended to be left blank

Chapter 1. Introduction and Background

1.1 Introduction

The dynamic between ‘vertical’ and ‘horizontal’ approaches to health interventions has been revisited in the last decade with attempts to reconcile the inter-play of vertical approaches and health systems. In health systems research, “complex”, “adaptable”, and “feedback-driven” are descriptors of the implicit nature of its primary objects of research, namely health systems or subsystems of care. There are few examples in the literature of the use of quantitative research methods to examine the impact of intervention-specific strategies and interventions on health systems performance. This thesis presents a *country health system tradeoffs case study* that examines the measureable impact of immunization-specific *readiness to deliver vaccination services* on immunization- and non-immunization service delivery performance in the health system of Afghanistan. Measures include inputs (infrastructure, health workforce, supply chain, etc.), outputs (access and health facility readiness, quality of care, etc.) and outcomes (health service coverage of both immunization- and non-immunization services) of health service delivery.

For this country case study, data were combined from annual national health facility assessments and periodic national household surveys carried out from 2007-2012 in Afghanistan. The case study uses a combination of quantitative and qualitative research methods, including regression models, causal loop diagrams (CLDs), and system dynamics modeling to examine within and between subsystem performance in the Afghan health system.

1.2 Health systems, conceptualizing and frameworks

A *system* is a set of "things" interconnected in such a way that they produce their own pattern of behavior over time, and the key to understanding their behavior is to examine their structure (Meadows, 2008). Therefore, a *health system* is a set of components that are interconnected and designed with the intention to support positive health outcomes. Health systems have been defined as "all organizations, people, and actions whose primary intent is to promote, restore, or maintain health" (WHO, 2000, 2007).

According to this definition, health systems encompass more than the structures and players involved in publicly delivered health services, expanding to include non-state actors such as nongovernmental organizations (NGOs), civil society organizations (CSOs), and the unregulated private sector. Health systems involve functions like financing, leadership, and governance in addition to service delivery, which has traditionally been their primary function. To describe health systems as complex is an understatement. Different modalities of exchange and development within systems (including health systems) are recognized through the acceptance of the complex adaptive systems perspective and unconventional system-growth behavior (Paina & Peters, 2012).

The importance of understanding health systems and improving health service delivery is not a new idea. The study of health systems has rapidly grown as a domain since the beginning of the 2000s (van Olmen, Marchal, Van Damme, Kegels, & Hill, 2012).[1] Between 2000 and 2005 a reinvigorated focus on health systems flourished with

[1] Health systems frameworks such as the Actors framework (Evans 1981), the Infrastructure Framework (Kiesczkowski, 1984), and the Roemer Framework (Roemer, 1993) arose as examples pre-dating the more

the underlying realization that the goals of targeted and narrow-focused interventions could not be met without strong health systems (Hafner & Shiffman, 2013; Travis et al., 2004; van Olmen et al., 2012). Specifically, the role of disease-specific and narrowly outcomes-focused programs has received increased attention (Rifat Atun, Weil, Eang, & Mwakyusa, 2010; Béhague & Storeng, 2008; Biesma et al., 2009; Closser et al., 2012; Cohen, Li, Giese, & Mancuso, 2013; Hanvoravongchai et al., 2011; Levin, Ram, & Kaddar, 2002; Rao, Ramani, Hazarika, & George, 2014)

As seen in the literature, health systems strengthening emerged as a catch-phrase and soon health systems frameworks such as the '6 building blocks framework' (van Olmen et al., 2012; WHO, 2007) appeared as evidence of the emerging interest in health system strengthening and the conceptualization of health systems accordingly. In general, frameworks reflect the prevailing paradigm of their time and the needs of the developer, including those that address the integration of focused disease control strategies (van Olmen et al., 2012). The six-building blocks framework was designed with the intent of promoting a common understanding of what a health system is and what counts as health systems strengthening (WHO-MPSCG, 2009).[2] It was created with the intent of informing governments about where to invest in health systems rather than serving as a framework for examining health system structure and behavior.

recent surge and interest in health systems following the publication of the World Health Report 2000 titled 'Health Systems: Improving Performance' [21, 28].

[2] Because many models have emerged in the past decade to address different nuances for conceptualizing health systems, it is difficult to imagine a "complete" or "ideal" model that can be applied in any given context and perhaps this should not be the goal. A better option may be to further discuss the choices made to use or create a given health systems framework.

1.3 Vertical programs in global health

Following the Alma Ata Declaration in 1978, the World Health Organization (WHO) and United Nations Children's Fund (UNICEF) were the primary enactors of the Health for All agenda. Thereafter in the 1990s the trends of globalization, marketization, and the occurrence of the AIDS epidemic contributed to the rise in global actor participation. Partially in response to the AIDS crisis and following the development of the Millennium Development Goals (MDGs), the actor landscape in global health shifted with the emergence of public-private partnerships resulting in global health initiatives (GHIs) and the preference for targeting specific priorities (van Olmen et al., 2012). Though not the only underlying current driving the use of vertical approaches, newcomers at that time such as the Bill and Melinda Gates Foundation (BMGF), the Clinton Foundation, the U.S. President's Emergency Plan for AIDS Relief (PEPFAR), and the Rockefeller and Ford Foundations did contribute to the more than doubling of resources for global health witnessed at the turn of the century (Dieleman et al., 2016; Ravishankar et al., 2007; van Olmen et al., 2012). The concept of health systems has since continued to shift following the WHO's recognition of the complexity of health systems and the similar recognition given shortly thereafter by the health systems research community (van Olmen et al., 2012).

GHIs are also referred to as Global Public-Private Partnerships and Global Health Partnerships.[3] Though no common definition can be found, GHIs are typically

[3] About 100 GHIs existed at the time of the WHO Maximising Positive Synergies Collaborative Group (WHO-MPSCG) report [22] with some of the most well-known of these including the Global Fund to Fight AIDS, Tuberculosis and Malaria (Global Fund); the Global Alliance for Vaccines and Immunization (GAVI); the US President's Emergency Plan for AIDS Relief (PEPFAR); and the World Bank Multi-Country AIDS Program (MAP). Their existence in the international aid framework is prominent, and they have been used to leverage large financial commitments between countries. The

characterized as disease-, intervention-, commodity-, or service-specific. Other commonly shared characteristics are their ability to generate and leverage substantial funding for their cause, their narrow focus on inputs, outputs, and outcomes evaluating one intervention rather than broad system improvements, and their direct country investments channeled through partnerships with NGOs and CSOs (WHO-MPSCG, 2009).

1.4 Vertical versus horizontal in global health

The debate about vertical versus horizontal paradigms in public health is longstanding and known to experts in the field. Using maternal health as a case study, Béhague and Storeng (Béhague & Storeng, 2008) aimed to elucidate factors associated with the vertical paradigm in current policy and research approaches. The authors identified the clear pressure to support vertical approaches due to competition, political influence, and the implicit normative power of scientific values like robustness that influences program design and evaluation rather than priority research questions and knowledge gaps. Simply stated, it is easier to generate consensus, disseminate findings, procure funding, and apply findings in a straightforward manner when aligning with the vertical paradigm as a researcher or policymaker. Verticality is entrenched in many actors' thought and behavior, making it difficult to accept different approaches to evaluating and conceptualizing health service delivery and systems of care.

To diverge from readily accepted methods means to take a risk that may affect the ability to procure funding, advance in career development, and gain or maintain political standing. Methods for achieving scientific rigor remain debated and unclear because of

---

common objective across these high-profile GHIs has been to reduce the burden of major diseases recognized for their public health importance, which is now under scrutiny for leaving out "systems" from efforts to improve population health.

the nature of health systems and system-wide interventions. It has been argued that health systems research requires the use of less revered research paradigms and non-traditional models, borrowing from or partnering with, established fields that have been addressing complexity and feedback for decades. This means going against the flow of "normative power of scientific values" (Béhague & Storeng, 2008), a choice that may be warranted in order to study the complex-, feedback-driven behavior of health systems without compromising rigor.

1.5 Define vertical and horizontal for this thesis

For the purposes of the research presented in this thesis, we will use similar characteristics to those used to describe GHIs in order to develop a working definition for vertical and horizontal approaches. A vertical approach is a disease-, intervention-, commodity-, or service-specific focused service delivery strategy that has its own management, logistics, and reporting systems. A horizontal approach spans disease-, intervention-, commodity, or service-specific focused approaches that is further developed (adapted) and monitored using indicators that span disease-, intervention-, commodity-, or service-specific boundaries.

1.6 Impact of vertical programs on health systems: tradeoffs?

1.6.1 Vertical programs and health systems

To date the following vertical approaches have been examined for their impact on health systems: HIV/AIDS, tuberculosis, new vaccine introduction, PEPFAR-focused activities, the polio eradication initiative, the measles eradication initiative, malaria, and childhood immunization as well as focused contracting initiatives for delivering health services (Biesma et al., 2009; Closser et al., 2012; Cohen et al., 2013; Griffiths et al., 2011; Hanvoravongchai et al., 2011; Hyde et al., 2012; Levin et al., 2002; Shearer, Walker, Risko, & Levine Orin, 2012; Susan A Wang et al., 2012). Overall, the most common positive effect of vertical programs on health systems is increased access and uptake of targeted health services typically measured by changes in coverage. Other hypothesized effects include the improved availability of essential supplies and drugs, replenished and strengthened health facilities, greater availability of qualified health personnel, improved capacity through in-service training, and increased demand and support for health services by the community partly through the increasing availability and accuracy of good quality health information (WHO-MPSCG, 2009).

Negative hypothesized effects include the disruption of basic health service delivery, the creation of parallel health information systems and supply chains, and distorting the availability and/or allocation of human resources and supplies/drugs. Evaluations of interventions designed specifically to take into consideration the comprehensive health system have typically focused on only one or two health system building blocks of the WHO framework. Few evaluations have attempted to conceptualize how such interventions may affect multiple health systems building blocks and the broader health system as a whole (Taghreed Adam et al., 2012).

1.6.2 Selecting a (vertical-natured) subsystem of the health system for this case study: Immunization

The contributions of immunization to children's health and overall public health are widely recognized. Global immunizations save an estimated 2.5 million lives per year (Macintosh, Eden, Luthy, & Schouten, 2017). Despite significantly protected health, vaccine-preventable diseases remain responsible for an estimated 1.5 million deaths among children every year (UNICEF, 2017).

The evolution of child health programs in developing countries has included two strategies: short-term, disease-specific initiatives and broader primary health care programs (Claeson & Waldman, 2000). The nature of immunization strategy as a whole is not entirely one or the other in terms of horizontality or verticality. It has solicited the input and involvement of many key players such as WHO, UNICEF, and BMGF.[4]

An *immunization system* is created and maintained to support positive, immunization-specific outcomes. Routine immunization could be called a core subsystem and area of care in country health systems. It often is a part of basic packages of health services. It has a horizontal nature that spans several vaccine-preventable diseases and varying target populations coupled with vertical program characteristics that include its campaign activities, intervention-specificity, disease elimination targets, and specific target populations and diseases. Routine immunization has been referred to as an *essential platform*, *critical subsystem*, and a component that is *both dependent upon and strengthening* the host health system (Clements et al., 2011; Shen, Fields, & McQuestion, 2014; Sodha & Dietz, 2015; Steinglass, 2013; Susan A Wang et al., 2012).

According to Gauri and Khaleghian (Gauri & Khaleghian, 2002), immunization strategies have notable characteristics that make them different from other health strategies. The authors described a stronger consensus among technical experts in the field, a shorter time-frame for policy in addressing stagnating and even declining

[4] Initiatives such as the GAVI Alliance Immunisation Services Support (GAVI-ISS), the Global Immunization Vision and Strategy (GIVS, WHO), Universal childhood immunization (UCI, UNICEF), PEI, and MEI in addition to programs like the EPI, IMCI (Integrated Management of Childhood Illness (IMCI), and Roll Back Malaria have formed to address specific aspects of child health.

coverage and new vaccine introduction, weak household demand for vaccination (compared to curative care), and weak support from providers in comparison to other areas of health reform such as provider payment and risk-pooling schemes (Gauri & Khaleghian, 2002). As children continue to be born, immunization-related activities, especially those encompassing routine activities, will remain a necessary investment for health systems worldwide. Focus has been given to temporary, all-in eradication efforts while the public image for systems like the routine immunization system suffer (Steinglass, 2013).

1.7 Immunization: program history and characteristics

1.7.1 Immunization: changes from the 1970s to present

Over the past few decades, improvements have been seen in the health of children with the decline of mortality rates from about 12.7 million in 1990 to 6.3 million in 2013 (WHO, 2015). Improved access to services such as vaccinations, oral rehydration therapy, and antibiotics for pneumonia along with improved social conditions are each in part responsible for the improvements in children's health (Duclos, Okwo-Bele, Gacic-Dobo, & Cherian, 2009). Despite gains in child survival, equity remains one of the central issues of progress in child health (Bryce, Victora, & Black, 2013).

More than forty years ago, in 1974, the WHO launched the EPI (Lim, Stein, Charrow, & Murray, 2008; Shen et al., 2014; WHO, 2011b). Shortly after the establishment of the EPI, a global goal for universal child immunization was developed at the World Assembly in 1977, a prerogative focusing on six basic antigens (i.e. diphtheria, pertussis, tetanus, measles, poliomyelitis, and tuberculosis) (Lim et al., 2008). The 1980s are known as the decade in which substantial progress was made on the child immunization front, a time period that includes the 1984 launching of a second major initiative, known as Universal Childhood Immunisation (UCI), aiming to meet 80% global immunization coverage. It represents a UNICEF partnership with other organizations and was a substantial influencer on mobilization of immunization funding, enabling UNICEF to declare in 1990 that the 80% coverage target had been achieved (Lim et al., 2008).

Since then, vaccination coverage has indicated that gains were stagnating or, worse, declining (Maekawa et al., 2007; Steinglass, 2013; WHO & SAGE, 2015). Programs have become increasingly complex since 1974 with rising costs, added vaccines in the routine schedule, hard-to-reach populations, increased demands on cold chain infrastructure and logistics, and exogenous threats like civil unrest and conflict (Shen et al., 2014). The summary measures for immunization progress/stagnation are not indicative of the substantial inter- and intra-country differences in coverage (Bosch-Capblanch, Banerjee, & Burton, 2012). The Global Alliance on Vaccines and Immunisations (now called Gavi, the Vaccine Alliance) was developed in response to slow and relapsing immunization progress to provide more vaccines to more children in more countries (Claeson & Waldman, 2000).[5]

1.7.2 Immunization construction: routine versus campaign activities

Immunization-related activities include those of continual and routine nature as well as those of campaign-based and episodic nature. Those of routine nature can be

[5] The GAVI initiative offers a range of support for children and mothers' health, including the immunization services support (ISS) that represents the funding specifically aiming to increase basic vaccine coverage. The GAVI Alliance is a public-private consortium with primary members include the WHO, UNICEF, the World Bank, national governments, public health and research institutions, the Rockefeller Foundation, the International Federation of Pharmaceutical Manufacturers Associations, and the Bill and Melinda Gates Foundation.

considered a more integral component of the health system whereas those of campaign-based nature tend to be non-continual attempts to sustain the gains made by routine activities. Routine immunization has been discussed as an actual sub-system of health systems, including ongoing activities that are intended to provide timely protection against common childhood diseases.

Routine immunization has been discussed as a platform from which new vaccine initiatives or other child health programs can launch. Through its continual activities, routine immunization could reduce the frequency with which campaign-based immunization initiatives (JSI, 2011; Steinglass, 2013) are needed. Sustained coverage and disease control, quality, and equity are the ultimate goals of routine immunization, reflective of the goals of the health systems within which they are embedded. Campaigns are intended as gap-fillers, i.e. supplements to the routine immunization that aid in maintaining coverage gains or improving immunization status to meet targets.

1.7.3 Measuring immunization performance

Monitoring and evaluation on vaccination uptake have been defined in terms of two indicators: coverage and/or in terms of timeliness (Bosch-Capblanch et al., 2012). Typically, coverage alone has been used to define the progress of routine immunization because of the ease of capturing the needed measures for its estimation. Coverage is defined as “the proportion of targeted children who have received vaccines”, and measurements of coverage of multiple doses of the same vaccine (e.g. third dose of Diphtheria-Tetanus-Pertussis vaccine, DTP3) and dropout rates help to describe the ability of the system to deliver multiple-dose vaccines (Bosch-Capblanch et al., 2012). DTP3 coverage is often used as an routine immunization coverage indicator mainly because DTP3 vaccine is delivered only in routine immunization activities and DTP3 coverage is indicative of system capacity to engage infants in three consecutive vaccination events (Bosch-Capblanch et al., 2012; Duclos et al., 2009; Lim et al., 2008; Shearer et al., 2012; Sodha & Dietz, 2015). Measles coverage has been used with DTP3 coverage to measure the strength of routine immunization (Sodha & Dietz, 2015; Steinglass, 2013), and additional aggregate measures that include fully-immunized children (all vaccines under the vaccination schedule received on time) and partially-immunized children have been used to describe in-country routine immunization status (Bosch-Capblanch et al., 2012; Favin, Steinglass, Fields, Banerjee, & Sawhney, 2012).

1.7.4 Factors associated with immunization coverage and improved routine immunization system performance

In general, studies suggest supply- and demand-side factors as well as individual, household, and higher-level contextual factors related to routine immunization coverage of which varying contexts are represented. Maternal education and knowledge have been shown to positively influence use of routine immunization services (Bishai, Suzuki, Mcquestion, Chakraborty, & Koenig, 2002; Maekawa et al., 2007; Sanou et al., 2009; Tao, Petzold, & Forsberg, 2013), and so has the level of both parents' education and how it may correlate with their knowledge of vaccines (Bosch-Capblanch et al., 2012; Sanou et al., 2009). Also at the individual level, the birth order of children has been found to affect use of routine immunization services (Bishai et al., 2002).

At the household level factors may include wealth, socioeconomic status, educational level, structure (nuclear versus laterally extended), and ethnicity (Bosch-Capblanch et al., 2012; Chan Soeung, Grundy, Duncan, Thor, & Bilous, 2013; Gauri &

Khaleghian, 2002; Maekawa et al., 2007; Sanou et al., 2009; Tao et al., 2013) as well as decision-making (Bosch-Capblanch et al., 2012) and power relationships (Gauri & Khaleghian, 2002) in the household. Location of residence related to proximity to health facilities (Chan Soeung et al., 2013; Gauri & Khaleghian, 2002; Hemat, Takano, Kizuki, & Mashal, 2009) and other community characteristics (i.e. local/social beliefs in vaccine, local governance, etc.) are contextual factors. Issues of trust in local health workers (Holte, Mæstad, & Jani, 2012; Ozawa, Paina, & Qiu, 2016; Ozawa & Stack, 2013), dissatisfaction with providers (Haddad et al., 2009; Sanou et al., 2009), vaccination social norms (Larson, Jarrett, Eckersberger, Smith, & Paterson, 2014), and behaviors such as use of antenatal care (ANC) services or facility-based deliveries (Gauri & Khaleghian, 2002; Hemat et al., 2009) have also been identified as demand-side factors associated with routine immunization coverage. Though caregivers' knowledge and attitudes have been identified as factors, few papers have quantified their relationship with routine immunization coverage (Holte et al., 2012). Moreover, Das & Das (2013) posit that in environments of high incidence of vaccine-preventable diseases and variation in vaccination, the success of parallel programs has linked back to trusted providers. Here household health seeking behaviors were based on trust in providers and vaccine information given by those trusted providers (Das & Das, 2003).

Supply-side factors (e.g. outreach activities, strength of cold chain, presence/participation of project/external partners, health personnel motivation, leadership, etc.) are also found to have an association with the accessibility, availability, acceptability, and affordability of routine immunization services that in turn affects coverage (Haddad et al., 2009; Tao et al., 2013). Immunization campaign activities have been found to improve coverage (Ryman, Trakroo, Ekka, & Watkins, 2012) and, though no empirical evidence has been presented, new vaccine introductions have been described by stakeholders as also having positive effects (Tao et al., 2013; S A Wang et al., 2013). However, these two factors have had mixed accounts of positive versus negative effects on routine immunization coverage, and informants have described that the impact depends on the strength of the underlying routine immunization subsystem (S A Wang et al., 2013). NVI has actually been shown quantitatively to have no association with routine immunization coverage (specifically using DTP3 vaccine coverage as a proxy) (Shearer et al., 2012; S A Wang et al., 2013) but rather other development and health system variables were found to be linked, such as the presence of armed conflict, coverage of ANC services, infant mortality, percentage of health expenditures that are private, and total health expenditures per capita (Shearer et al., 2012). In the context of Afghanistan, researchers have also presented similar findings that link the success (or lack thereof) of routine immunization to discontinuity in service provision, facility-based deliveries, use of ANC, proximity to nearest health facility sites providing vaccines, and the amount of contact with outreach activities in rural areas of the country (Hemat et al., 2009).

1.7.5 Evidence on strategies for achieving improved routine immunization system coverage

Chopra et al. (2012) used a three-step approach to aid in understanding methods for improving child survival, health, and nutrition through increased coverage of evidence-based interventions. Their process involved first identifying intervention delivery channels, then determining whether current modes of delivery for interventions can be improved by changing within or across channels, and finally conducting a meta-review of published and unpublished accounts of effective strategies created to overcome supply and demand bottlenecks (Chopra, Sharkey, Dalmiya, Anthony, & Binkin, 2012). Bottlenecks that were considered are those in the areas of availability, accessibility, utilization, continuity, and effective coverage of intervention services. The authors concluded that the evidence supports strategies that either shift interventions from one delivery channel to another or shift how services are delivered within channels, strategies that make use of the private sector for provision of services, and strategies that focus on reduction of financial barriers to access (Chopra et al., 2012). They also concluded that demand barriers are just as important as supply bottlenecks, and equally warrant the need for systematic research.

In 2005 Pegurri, Fox-Rushby, and Damian conducted a systematic review of the evidence on interventions designed to improve coverage of the immunization system, aiming to identify the interventions that could be most reliably accepted as effective and cost-effective. Supply-side interventions focused on training in the classroom or by peers in the field as well as on increasing monitoring and supervision (Pegurri, Fox-rushby, & Damian, 2005). Outreach activities via teams or community health workers (CHWs) as well as modification of immunization schedules to match more convenient timing of visits to health facilities were other interventions. Demand-side interventions included re-organizing clinical procedures to reduce waiting times, reducing missed opportunities by vaccinating when children were present at the health facility even if ill, sending reminders sometimes even through school children or channeling (i.e. door-to-door canvasing) to address non-attendees, and increasing awareness and knowledge through media campaigns. Strategies that addressed both demand and supply included mainly mass campaigns but also those that reorganized the immunization system on dimensions like training, information systems, or decentralization of service delivery.

Pegurri et al. (2005) suggest one possibility based on the highest percentage increase in coverage, which produces the use of CHWs and channeling activities as the most successful according to their review. Chopra et al. (2012) add that increasing the number of health posts as well as remote or mobile health teams have been shown to produce moderate-to-high EPI vaccine coverage gains. Though there was no significant difference in performance between interventions targeting supply versus demand, it is noted that some supply strategies, such as those addressing availability, are logical precursors to addressing demand. The wide-variation in average costs referring to the same type of intervention make it difficult to draw conclusions from cost-effectiveness comparisons. However, within country comparisons indicate that outreach teams have higher average incremental costs than do mass campaigns, and the costs of both are higher than the average total costs of routine immunization services. Moreover, while outreach campaigns and child health days have been shown to increase coverage, there is mixed evidence on whether routine immunization and/or exposure to campaigns ensure that children receive all doses in the recommended EPI vaccination series (Helleringer, Asuming, & Abdelwahab, 2016; Mounier-Jack, Edengue, Lagarde, Baonga, & Ongolo-Zogo, 2016; Ryman et al., 2012).

1.7.6 Immunization strategies and immunization systems

A literature review revealed findings from studies examining the relationship between vaccine-specific interventions (i.e. eradication initiatives or new vaccine introduction) and routine immunization (Griffiths et al., 2011; Levin et al., 2002; Ryman et al., 2012; Shearer et al., 2012; S A Wang et al., 2013) but few specifically looking at the impact of routine immunization on health system performance. A common theme appears to be the exploration of the effects of introducing new vaccines on immunization or immunization weeks on routine immunization (Chopra et al., 2012; Levin et al., 2002; Shearer et al., 2012). Studies suggest cold chain and logistics capacity, injection safety, disease burden, and surveillance were positively impacted. Investigators from another study found that introducing new vaccines did not impact routine immunization coverage, cold chain capacity had to increase, reduced healthcare costs may be associated, and training and education for health workers as well as social mobilization were factors in effective implementation (Hyde et al., 2012).

1.8 Health systems research, complexity, and systems modeling

The good news is that members of the health policy and systems research community and other researchers, practitioners, and policymakers are recognizing the value of health system integrity both for the delivery of routine services and during emergencies (Taghreed Adam et al., 2012; Gilson, Hanson, Sheikh, Agyepong, & Ssengooba, 2011; WHO, 2007). In the most recent years investments have been tracked and shown to have been shifting from disease-focused initiatives (e.g. malaria, tuberculosis, HIV/AIDS) to MDG and Sustainability Development Goals (SDG) centered activities (Dieleman et al., 2016).

Rooted in systems science, system dynamics (SD) is a methodological approach capable of deploying the systems perspective and applicable to the push-pull of system-system (or subsystem-system) relationships. It considers the complexity of systems, interpreting real-life systems into computer simulation models that allow one to see how the structure and decision-making policies in a system create behavior (Forrester, 2009). The SD modeling process allows for the modeling of complex behaviors of organizational and social systems that are the result of ongoing accumulations of people, material, or financial assets, information, or even biological or psychological states as well as balancing and reinforcing feedback mechanisms (J. B. Homer & Hirsch, 2006).

SD models make implicit assumptions explicit, identify gaps in knowledge and data, and highlight sensitive areas (leverage points) for system change (Meadows, 1999). These models can reliably determine the future dynamic consequences of changes to one part of the system and effects on another. Rather than simplifying systems to a series of linear pathways, an SD modeling approach allows for examining repeated and feedback interaction within and between subsystems over time (Hirsch et al., 2007; Lyon et al., 2016). Behavior is driven by feedback loops that may change, increase, or lessen the interaction among different components and processes within a system. The product of accumulated feedback may be a new summation of system behavior that is different from what was anticipated.

SD model development is an iterative process. It involves the specification of three components (Forrester, 2009): stocks, flows, and feedback loops. Stocks are the primary outcome of SD models and can represent any variable that is expected to change as a result of the specified flow and feedback loop parameters (Lyon, Maras, Pate, Igusa, & Vander Stoep, 2016). Stocks are modified by inflows and outflows that change their levels. SD model mathematical notation is unambiguous; models and assumptions are described explicitly. Language involved in SD models is often clearer, simpler, and more precise than spoken language. SD models are not derived statistically from time-series data; instead, they are statements about structure and the policies that guide decisions. SD models allow alternative policy levers and scenarios to be tested. By using sensitivity analysis on the system parameters, the resulting behavior of complex structure of systems can be translated into practical actions (Lyon et al., 2016) (e.g. increasing the number of health workers delivering vaccination produces what system behavior, or improving the knowledge of logistics and vaccine management produces what system behavior). They can predict unintended and intended consequences and time-delayed effects. An SD model is only as good as the expertise that lies behind its formulation as well as the explicitness of assumptions and sensitivity tests of those assumptions.

SD models have helped make significant contributions to addressing epidemiological issues, issues of health care capacity, health care delivery, and patient flow management (J. B. Homer & Hirsch, 2006). The only example specifically using SD modeling for examining the immunization sub-system as a whole comes from Rwashana and colleagues in Uganda (A. S. Rwashana, Williams, & Neema, 2009; A. Rwashana & Williams, 2008). However, Rwashana and colleagues aimed to understand immunization healthcare problems as well as how to improve immunization coverage effectiveness through the development and simulation of a healthcare policy design model.

1.9 Study and country context

Afghanistan comprises a geographical area of 652,000 square kilometers and population of more than 32 million people with about 73 percent of Afghans living in rural areas (The World Bank & Ministry of Economy, 2016). Its history marks the rise and fall of leadership as well as the chronic instability of the “state” and its fluctuating legitimacy and accountability. More than three decades of conflict and unrest represent Soviet invasions and control between 1978 and 1989 followed by factional fighting and rule of the mujahedeen until the emergence of the Taliban in 1994, the latter of which resulted in extreme restrictions placed on the Afghan people (Akseer et al., 2016; Lopes Cardozo et al., 2004). Following the fall of the Taliban in 2001, the current structure of government is unitary with all political authority vested in the government in Kabul, determining provincial and district administration powers and responsibilities (WHO, 2013). The period of 2004-2012, immediately following the re-establishment of a governing body, was a period of rapid health systems development in Afghanistan.

Known as a country that has endured hardship, Afghanistan is also a place where many world-renowned institutions have taken a stake in the well-being and development of the country and people. By 2011 Afghanistan received aid in the amount of more than 50 percent of its gross domestic product (GDP) from mainly six donors (of the 62 total donors) with the U.S. being the largest, contributing about one-third of all aid since 2001 (Goodhand & Sedra, 2010). In the health sector, the public health system is predominately supported by funds received from donors (Sabri, Siddiqi, Ahmed, Kakar, & Perrot, 2007) with some estimates as high as 90% of funding coming from international donors (Steinhardt et al., 2009). With heavy involvement of funders in the rebuilding of Afghanistan, many experts are concerned about the lack of clear mechanisms through which international donors' stated commitment to country ownership and partnership translates into fragile states or post-conflict settings (Goodhand & Sedra, 2010).

1.9.1 Health and development in Afghanistan

Afghanistan ranks "worst" or at the very least "among the worst" in many contexts. According to the 2015 Mothers' Index, Afghanistan ranks 152 among 179 countries for its poor state of maternal health, signifying some improvements since its 2011 status as "worst" of 164 countries (Save the Children, 2012, 2015). It is a country that is the ninth of ten countries contributing to nearly two-thirds of all newborn deaths (2 of 3 million annually) (Save the Children, 2013) and a place where one in every 49 women have the chance of eventually dying from a maternal-related cause (Save the Children, 2015). Children under five years of age die at a rate of about 91 deaths per 1000 live births, neonates at a rate of 36 per 1000 live births, and life expectancy at birth is 61 years of age (UNICEF, 2016a).

Gross National Income (GNI) per capita in 2016 was reported at 680 USD (UNICEF, 2016a). An estimated 40% of girls are married before the age of 18 years (Save the Children, 2013), and the total fertility is estimated to be about 4.7 children (UNICEF, 2016a). Though progress has been made in improving the health status of mothers and children, these two areas remain central priorities for the country.

Afghanistan is one of the three polio-endemic countries left in the world (Global Polio Eradication Initiative & World Health Organization, 2017). In 2001, measles epidemics were responsible for the death of 35,000 children, and until 2003, measles killed an estimated 30,000 to 35,000 Afghan children annually (Gaafar, Moshni, & Lievano, 2003; Mofleh & Ansari, 2014). With the support of international and national partners, the Afghan Ministry of Health implemented a series catch-up measles vaccination campaigns in 2001-2002, 2003, 2006-2007, and 2009 (Mofleh & Ansari, 2014). High morbidity and mortality associated with vaccine-preventable diseases are still serious health concerns for the country, and immunization coverage disparities exist throughout regions of the country. About one-fifth of Afghan women and children have never been immunized against diseases (UNICEF, 2016b).

According to the State of the World's Children Report (UNICEF, 2016a), DTP3 vaccination coverage was 75% while coverage for the Bacillus Calmette-Guérin (BCG) vaccine, first dose of measles vaccine (Measles1), and the third dose of polio vaccine (Polio3) were measured at 86%, 66%, and 75%, respectively. These indicate different capacities to reach children for vaccination because of the different recommended ages for each dose. As often is the case, differences exist between coverage estimates calculated from administrative versus survey data. According to the comprehensive multi-year planning (cMYP) 2011-2015 report, estimates varied by as much as 15 to 21 percentage points for measles and DTP3/OPV3 coverage, respectively (MOPH, 2012b).

1.9.2 The Afghan health system

Over thirty years of conflict and political unrest, internal factions, and an ineffective government often associated with the era of the Taliban regime (1994-2001) contributed to a devastated health system (Acerra, Iskyan, & Qureshi, 2009). In 2002, immediately following the fall of the Taliban regime, health services were provided mostly by NGOs (Arur et al., 2010) with an estimated 80% of existing health facilities under their management (Strong, 2003). Following the establishment of the Islamic Transitional Government of Afghanistan in 2002, the government's National Development Framework included the creation of fourteen separate development programs (MOPH, 2012a). The Ministry of Public Health (MoPH) established the

Consultative Group on Health and Nutrition to consult with and coordinate strategic planning among donors, line ministries, NGOs, UN agencies, Embassies, and International Assistance Forces.

Concerned for rapid development of health system infrastructure, outreach to the largely rural country population (more than 80%) (MOPH, 2012a), and addressing the high rates of maternal and child mortality, the Consultative Group on Health and Nutrition promoted the implementation of a basic package of health services (BPHS), a core service delivery package delivered in primary health care facilities via a network of international and local NGOs (Edward et al., 2009; Sabri et al., 2007). As a result of its ratification in 2003, the BPHS uses both contracting-in and contracting-out mechanisms and has allowed for an estimated 77% of the Afghan population to live in a district where health services were provided via contracted partners in 2006 (Palmer, Strong, Wali, & Sondorp, 2006). Since this time, two revisions of the BPHS have been completed, the first in 2005 and the second in 2010, that have included identifying additional health priorities (e.g. mental health, disability services, eye care services, etc.) as well as standardization of health infrastructure. The BPHS functions through six different sites, including Health Posts (HPs), health Sub-Centers (SCs), Basic Health Centers (BHCs), Mobile Health Teams (MHTs), Comprehensive Health Centers (CHCs), and District Hospitals (DHs). BPHS services are offered at three levels of health facilities, including the BHCs, CHCs, and the outpatient and maternity wings at DHs.

Following its focus on the provision of primary care through the BPHS, the MoPH recognized the need to address hospital care in order to build a more complete health system. The Essential Package of Hospital Services (EPHS) was endorsed by the

MoPH in 2005, which recognized a functioning hospital system that could accept referrals of complicated cases and conditions from HPs, BHCs, and CHCs (MOPH, 2012a). The EPHS outlines hospital services, diagnostic services, necessary equipment, the Afghanistan Essential Drug List by hospital type, and the minimum and recommended staffing levels (MOPH, 2012a). Figure 1 depicts the relationship between the BPHS and the EPHS health facilities.

The BPHS will remain the primary focus for the purposes of the proposed research, as "immunization" is one of the primary components of it and not the EPHS. It contains seven elements, one of which encompasses child health and immunization strategy (Table 1).

Three donors, including the World Bank, the European Commission, and the United States Agency for International Development (USAID), primarily support the health system. Approximate cost breakdown by donor based strictly upon the number of BPHS facilities they support would distribute as 37%, 19%, 24%, and 1% across USAID, EC, World Bank, and the Gavi Alliance support with the remaining costs being incurred by the MoPH and others (MOPH, 2012a). Afghanistan's approach to rebuilding its health system has included the use of several contracting modalities as part of its strategy to increase access to basic health services. Agreed upon by many researchers, the contracting of health service delivery to non-state providers has become a widespread approach to implementing health services in developing countries (Bhushan, Keller, Schwartz, Bank, & Economics, 2002; Trani, Bakhshi, Noor, Lopez, & Mashkoor, 2010). Afghanistan's health system has implemented 'contracting-in' and 'contracting-out' mechanisms under which services are provided by non-state providers, namely semiautonomous government agents and NGOs, respectively. Though the BPHS was reported to be implemented in districts where as much as 85% of the population resides (MOPH, 2012a) [1], it has also been estimated that the health worker to population ratio in-country is around only 6-7 health workers per 10,000 people (SavetheChildren, 2013).

According to the most recent 2012-13 national balanced score card (BSC), more than one-third of indicators (calculated on a scale of 1-100) showed a minimum of a five-percentage point increase, demonstrating overall good progress in the health sector. The following discussion on national performance comes from the 2012-13 BPHS BSC report (Ministry of Public Health, Johns Hopkins Bloomberg School of Public Health, & Indian Institute of Health Management Research, 2013). Though overall scores sustained good progress and improved with no declines nationally, varying performance by provinces and by domains of the BSC indicate needed attention. The domain of Client and Community Responsiveness remained in good standing for performance for each of its indicators where the Client Satisfaction and Perceived Quality of Care Index national median score was 75 and the Community Involvement in Decision-making at BPHS Facilities improved from 80 to 86 since the 2011-2012 results. One clear weakness under the Physical Capacity domain is the area of infrastructure, though improvements have also been seen. The Quality of Service Provision domain indicates variability where providers have been found to have good practices in assessing patients (Clinical Background and Physical Exam Index median score of 80) yet less good practice related to Client Counseling and Time Spent with Clients (median scores of 33 and 12, respectively). The Human Resources domain is similar with the median Health Worker Motivation Index score remaining high and improvements seen in the Timeliness of

Salary Payments and Health Worker Knowledge Scores (72, 72, and 70, respectively) while the Minimum Staffing Guidelines are not being met at facilities and Regular Training Opportunities are not available for staff (median scores of 24 and 9, respectively). Performance related to Management Systems has improved with regard to the use of Health Management Information System (HMIS) data, but Financial Systems remains a very weak area (median score of 3).

1.9.3 Immunization policy in Afghanistan

The restructuring of the EPI in Afghanistan began in 1994 with a series of National Immunization Days as part of polio and measles eradication initiatives as well as an EPI acceleration campaign all implemented on a national scale (Hemat et al., 2009). The EPI is managed under a 3-tier management system at the national (Preventive Medicine & PHC Directorate), provincial (provincial health directorate including EPI management teams), and district levels (District Public Health Officer). In terms of actual vaccine service delivery, these activities are a part of the BPHS under which all planning, staffing, equipping, training, and supervising of the activities are under the responsibility of the contracting NGO (MOPH, 2012b). Primary actors involved in the EPI in Afghanistan include the WHO, UNICEF, and GAVI as well as the International Committee of the Red Cross (ICRC) and other NGOs. The WHO provides much of training and acute flaccid paralysis (AFP) surveillance as well as planning for polio eradication efforts, and it offers additional supportive training and social mobilization efforts. UNICEF is responsible for the provision of vaccines in the country in addition to auto-disable syringes and safety boxes. It also supports the efforts under the polio eradication and MNT activities. Gavi, the Vaccine alliance, acts as a significant source for financial support to strengthen overall immunization in the country and is responsible for awarding four grants to the Afghan government since 2003 (MOPH, 2012b). NGO providers including the ICRC are responsible for the actual provision of vaccine services under their BPHS contractual terms of agreement.

In 2004, it was estimated that about 58% of BPHS facilities offered routine immunization services (MOH, 2004). According to the 2010 revisions of the BPHS, vaccines are to be stored at each of the subcenter, basic health center, comprehensive health center, and district hospital sites. Mobile health teams are to have both a cold box and vaccine carrier, too. All routine EPI activities including all antigens are to be carried out at each of the facility levels under the BPHS except for health posts where only support is offered. In general, most of the remaining EPI activities such as outreach and supplementary immunization activities, disease surveillance and case reporting, outbreak response, and vitamin A supplementation are to be carried out at all facilities levels offering BPHS services (Table 2).

Under the cMYP for the 2011-2015 period, immunization-related activities are divided into two categories, including: 1) accelerated disease control activities, and 2) routine EPI system components (MOPH, 2012b). The three main areas under disease control include those related to polio, MNT, and measles. The service delivery strategy under polio and measles related activities include largely national immunization days and campaign activities. Because polio has remained endemic in Afghanistan, a fourth dose of the oral polio vaccine (OPV4) was introduced to the routine immunization schedule in 2003 (Hemat et al., 2009).

National immunization days and sub-national immunization day activities are carried out at annually least four to five times each in order to curb and eliminate polio in the country, and according to the cMYP 2006-2010, national immunization days for polio eradication have been ongoing since 1997 (MOPH, 2012b). Supplementary immunization activities for measles were carried out immediately following the Taliban and have been carried out sporadically since 2003 (e.g. supplementary immunization activities in 2003, 2006, 2009, 2011). According to Hemat and colleagues (2009), vaccination strategy also includes the use of maternity centers in Afghanistan with policy requiring that mother and newborn not be allowed to be discharged unless the child has received the BCG vaccine and the first dose of the OPV. One hypothesis for why OPV coverage has remained lower than possibly expected considers underreporting by caregivers, though no empirical proof of this has been provided. In 2011, the AFP/EPI surveillance system confirmed 2,291 measles, 80 polio, and 20 neonatal tetanus cases (MOPH, 2012b).

Routine EPI system components included monitoring of coverage estimates for the four primary vaccines, the introduction of new vaccines such as the pneumococcal and rotavirus vaccines, routine surveillance for AFP, measles, and neonatal tetanus cases, cold chain and logistics functionality, and vaccine supply. In 2009, the EPI strategy included a switch from the use of the DTP vaccine to Pentavalent, which combines five different vaccines in a single vial to protect against five diseases: DTP, hepatitis B, and Haemophilus influenza type B (Hib). This was largely in response to estimated 11,000 and 14,000 annual deaths of Afghan children due to HBV-induced liver disease and Haemophilus influenza (MOPH, 2012b). Though the change was made in the type of vaccine used to address diphtheria, tetanus, pertussis, hepatitis B, and Haemophilus influenzae meningitis, the capturing of this information has not been adapted included in immunization cards given to caregivers to track a child's immunization history have not changed from including record of DTP3 to PENTA receipt. The schedule for routine immunization is presented in Table 3.

There are three parallel surveillance systems with the AFP/EPI system operating 564 sentinel and 6,000 reporting sites, the disease early warning system operating 280 sentinel sites, and the HMIS data collected passively from about 1,700 facilities in the country (MOPH, 2012b). Additionally, lab-based surveillance for Rotavirus, Pneumococcal pneumonia, and Meningitis began in 2007 in anticipation of the introduction of new vaccines. Though a reporting system for adverse events following immunizations (AEFI) exists, it has been reported that it does not function well (MOPH, 2012b).

The cold chain expansion at the national, regional, and provincial levels was completed to accommodate anticipated new vaccines for introduction as well as those required for mass national immunization days and SIA activities totaling 97 m^3 capacity nationwide. It is said that the system functions well at all levels, but monitoring of wastage and forecasting still remain areas of focus (MOPH, 2012b). Recently nine cold chain officers were trained at the national EPI office on vaccine and cold chain management under the support of WHO and UNICEF (MOPH, 2012b).

Regarding human resources related to immunization activities, insufficient salary levels and poor incentives remain issues that affect turnover rates. Advocacy and communication efforts have included mainly community mobilization and awareness efforts, partly by contracting six national and international radio/television stations to regularly broadcast service announcements on the importance of immunization. The cMYP 2011-2015 emphasizes the needed to conduct district level mobilization and education efforts.

1.10 Study design

This thesis research makes use of a case study design focused on country health system tradeoffs. It examines the relationship between *readiness of the health system to deliver immunization-related services* and the *outcome performance of immunization-related service delivery* as well as *other non-immunization service delivery*. The study uses data from annual national health facility assessments and periodic national household surveys, which together provide information on the performance of the health system at different stages of the evaluation process (input/process, output, outcome, and impact). Paper 2 (Chapter 4) also makes use of literature and expert feedback.

Paper 1 (Chapter 3) presents a study examining the association between system readiness to deliver immunization services and immunization coverage outcomes in Afghanistan using marginal models. Readiness measures such as those related to cold chain functionality, health workers and training, vaccine stocks, and others were selected as measures of performance at the health facility serving as inclusive yet basic measures for immunization-related supply-side performance in Afghanistan. The outcome of interest is the vaccination coverage of the third dose of pentavalent among 12-23-month-old children.

Paper 2 (Chapter 4) presents a study aimed to identify the pathways through which system *readiness* to deliver immunization services may affect immunization and non-immunization outcomes in Afghanistan. CLDs were constructed based on a rapid review of the literature, findings from the first study (Chapter 3), and an expert feedback process. CLDs were developed according to subsystems of the immunization system, their components, their structure, and their connections. The immunization outcome of interest was again the vaccination coverage of the third dose of pentavalent among 12-23-month-old children. The non-immunization outcomes of interest were: use of ANC services, skilled birth attendance (SBA), children with acute respiratory-infection (ARI)-like symptoms who were taken to a health facility for treatment, and tetanus toxoid vaccination. Using these CLDs as well as findings from preliminary regression analyses (Chapter 3), Paper 3 (Chapter 5) presents a study that uses SD modeling to simulate the impact of immunization service readiness on immunization and non-immunization performance in the Afghan health system. This is a model-confirmatory exercise using SD modeling, examining system structures and mechanisms that were previously conceptually mapped in the CLDs (Chapter 4).

1.10.1 Significance and innovation

Health systems are recognized for their important role in providing routine services (Shen et al., 2014; WHO, 2011b; WHO & SAGE, 2015) and supporting resiliency during health or other humanitarian crises (Hare, 2014). Evidence suggests the importance of key service platforms in health systems and their potential for bolstering other parts of the health system (LaFond et al., 2015; Shen et al., 2014; Steinglass, 2013). Most evidence thus far has been generated using qualitative methods, and findings from quantitative analyses have resulted from linear, reductionist approaches. For this thesis research, these methods are less appropriate to answer questions about *complexity* in systems. This thesis research represents a progression that bridges conventional quantitative methods in public health research with conventional quantitative methods in systems research to examine system structure and thereafter system behavior.

SD has a growing presence in public health literature, specifically regarding immunization. Quantitative methods (e.g. SD models) may be better for representing defined structure and assumptions of a system in the real world while qualitative methods (e.g. CLDs) tend to be more pluralistic and holistic, generating debate and insight about the real world (Cavana & Maani, 2000). Given the complex nature of health systems, it is appropriate to model their internal and external-reaching relationships as a comprehensive system. Conventional analytic methods may be less well-suited for addressing the dynamic complexities that characterize public health issues, which are often characterized by situations where population needs change over time and in which risk factors, diseases, and health resources are in a continual state of interaction and flux (J. B. Homer & Hirsch, 2006).

The immunization system was selected as an example of one *platform* in the Afghan health system (as well as most countries). Vaccination is recognized as one of the greatest achievements in public health history. But since the inception of the EPI in 1974, the program has become increasingly complex with new vaccines, protocols, and structures. It has vertical characteristics (i.e. disease-, intervention-, content-, population-specificity) but also horizontal characteristics (i.e. routine schedules, part of BPHS). An understanding of the immunization system could serve as a lesson of SD in health systems research. Qualitative and quantitative SD approaches can highlight the necessity for understanding and accounting for complexity when tackling system strengthening and avoiding system distortions.

1.10.2 Thesis research questions

The primary predictors of interest for studies in this thesis capture *immunization-related readiness* of the Afghan health system. *Readiness* was selected as a proxy for performance at the health facility serving as inclusive yet basic for measuring supply-side performance in Afghanistan. *Readiness* predictors were created from data collected during the annual health facility assessments in Afghanistan in 2008-2012. Consideration was given to measures specific to vaccine delivery such as vaccine stock, cold chain functionality, staff and clinicians for vaccination, information systems, and other infrastructure to create this measure. Primary outcomes of interest are *coverage estimates for immunization- and non-immunization related services*, and these were calculated using data from two national household surveys in 2007-2008 and 2012-2013. Coverage is defined as the proportion of targeted population that has received a given service (e.g. DTP3 vaccine, skilled birth attendants at delivery, etc.). Predictors for contextual factors were also created from these data.

Paper 1:

1) What is the association between *readiness of a health system to deliver immunization-related services* and *immunization outcome performance* (coverage) at the provincial level in Afghanistan?

Paper 2:

1) What are the main components of the Afghanistan immunization system that represent its *readiness to deliver immunization-related services* and how do they connect?
2) What are the different pathways through which immunization system components may affect immunization performance and non-immunization service performance?

Paper 3:

1) What are the significant immunization system components and their anticipated year-to-year impact on immunization and maternal health service coverage in Afghanistan between 2007-2008 and 2012-2013 time periods?

1.10.3 Conceptual framework

Steinglass (2013) discusses two general schools of thought for conceptualizing the relationship between routine immunization and HS (Figure 2). One school of thought posits that investments toward health systems strengthening produce the strengthening of routine immunization. The second supposes that investments in GHIs (disease-focused strategies) produce the strengthening of both routine immunization and health systems more broadly. Measurements for these two approaches have included impact measurements such as reduced all-cause child mortality and reduced disease-specific incidence in children for the former and the latter of the two thought paradigms, respectively. Both schools of thought promote investment according to their respective pathway, yet Steinglass (2013) proposes that each could more strategically find middle ground by advocating for a common direct investment strategy focusing on routine immunization strengthening "as an integral part of the broader health system to achieve disease reduction goals" (Steinglass, 2013).

When considering the previously outlined pathways, the routine immunization – health system relationship can be visualized in two fashions: one that is an arguably more standard way of thinking in a linearly progressive model versus a model that captures the layered or embedded relationship that may more clearly allow for correlative and effect modifying exchanges (Figure 3). Immunization strategies represent a content-specific initiative that, as previously discussed, fits the definition of "vertical" strategies. However, the degree to which routine immunization becomes an integral component of the health system is enough, in some cases, for experts in this area of study to separate it from campaign-based immunization strategies and recognize it as a sub-component or even sub-system of the entire health system.

Building on the second school of thought, routine immunization can be examined through a systems lens. Routine immunization is an ongoing system and must sustain high performance functioning as newborns continue becoming a part of our world. This system must continue to provide on-time protection, sustain gains made through the pursuit of campaigns, and serve as a platform from which the launching of new vaccines can take place. In the same way that the process of health service delivery in health systems models includes characteristics of accessibility, acceptability, availability, and affordability of services, strong immunization sub-systems similarly require these qualities as well as improved performance measured by effective timely coverage (good quality and equitable) that is sustainable, improved health outcomes, and improved impact. In this sense routine immunization is a sub-system that has similar functions as the overarching health system but more focused outcomes that include specifically improved and sustained routine immunization coverage and disease control.

The idea of routine immunization as a sub-system is emerging in literature (Levin et al., 2002; Steinglass, 2013; S A Wang et al., 2013). Trade-offs exist regardless of the direction from which we choose to approach the routine immunization-health system relationship. Strengthening the routine immunization sub-system may mutually reinforce the health system or cause distortion, and similarly strengthening the health system may directly influence the national immunization program in a positive way or preclude measureable impact.

Under John Snow International (JSI), the ARISE project (Africa Routine Immunization System Essentials) identifies and documents interventions that drive strong routine immunization system performance and analyzes their potential for diffusion, at scale, throughout sub-Saharan Africa (JSI, 2011). A model (Figure 3) was created to depict the relationship between routine immunization sub-system and health system including the primary determinants of routine immunization performance and influence of country and global level contexts. This model was presented as a product of the JSI ARISE landscape analysis (JSI, 2011).

Beginning in level three of the routine immunization system performance framework, the overarching goal of the immunization system (i.e. performance) has been defined by quality, sustained coverage, sustained disease control, and equity. The process measures that should contribute to good performance include measures of availability, acceptability, affordability, and accessibility of immunization services. The addition of primary determinants affecting immunization performance completes the module depicting the immunization subsystem as a component of the health system. Level two consists of the country health system that is in direct exchange with the immunization subsystem, and the performance of both is affected by the global/regional and country contexts. The shaded oval includes the process through which countries translate vertical programs into relevant, country-specific policies, programs, interventions, strategies, investment practice, and innovations. The framework is a comprehensive example of conceptualizing the routine immunization – health system relationship, and it allows for the strengthening of the immunization subsystem to provide for health system strengthening. It will be a guide for the analysis plan of the proposed study.

1.11 Organization of the document

The remainder of this thesis is centered on three papers presented as Chapters three, four, and five. Chapter two describes the data sources used for each of the three papers. Chapter three presents findings from a study that examined the association between annual health system readiness to deliver immunization-related services and current immunization coverage in Afghanistan using regression methods. Chapter four presents a study that defined immunization system structure in Afghanistan using CLDs, which includes system components and pathways of behavior. Chapter five presents a system structure confirmatory exercise using SD modeling, which builds on the CLDs developed in chapter four. Finally, chapter six summarizes key findings for the full body of thesis research, presents conclusions, and discusses recommendations. Tables and figures are continuously numbered throughout the full thesis manuscript but are presented at the end of their respective chapters. Supplementary tables, figures, or background are presented in Appendices at the end of this thesis.

An outline of remaining chapters is as follows:

- Chapter 2: Data source description
- Chapter 3: Paper 1: Examining the association between health system readiness to deliver immunization-related services over time and immunization coverage in Afghanistan: using secondary data and regression tools to explore health subsystem readiness and performance
- Chapter 4: Paper 2: The subsystems of an immunization system: using causal loop diagrams to identify pathways through which readiness to deliver immunization services may affect health service outcome performance in the Afghan health system
- Chapter 5: Paper 3: A system structure confirmatory exercise using SD modeling: examining anticipated impact of immunization system readiness components on immunization and maternal health service outcomes in the Afghan health system
- Chapter 6: Summary of findings, conclusions, and recommendations

1.12 Chapter 1 Tables and Figures

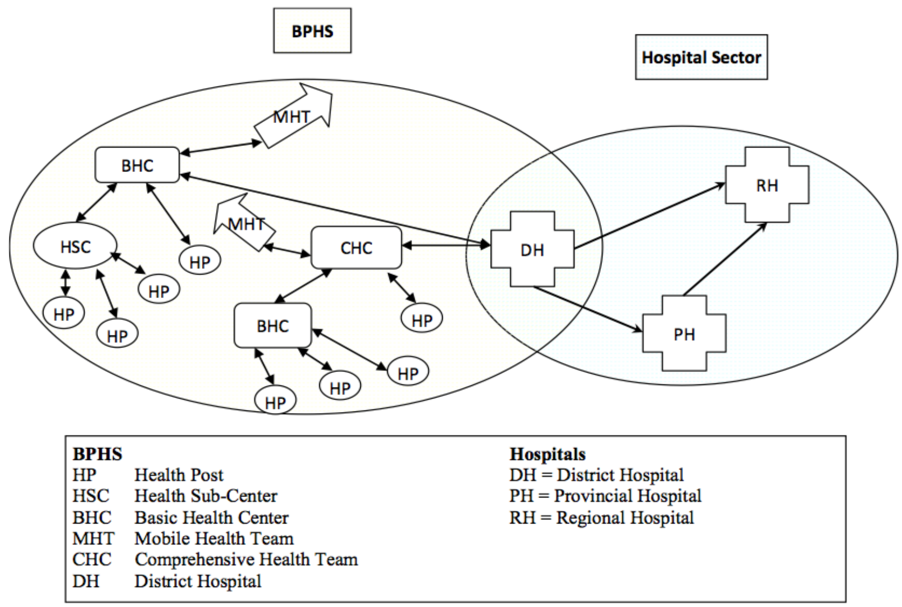


Figure 1. Schematic of health system in Afghanistan: the Basic Package of Health Services and the Essential Package of Health Services (MOPH, 2012a)

Table 1. Seven elements of the Basic Package of Health Services outlined in the latest plan revisions (MoPH, 2012a)

Maternal and newborn care	Antenatal care
	Delivery care
	Postpartum care
	Family planning
	Care of the newborn
Child health and immunization	Expanded Program on Immunization (EPI)
	Integrated Management of Childhood Illness
Public nutrition	Prevention of malnutrition
	Assessment of malnutrition
Communicable disease treatment and control	Control of tuberculosis
	Control of malaria
	Prevention of HIV and AIDS
Mental health	Mental health education and awareness
	Case identification, diagnosis, and treatment
Disability and physical rehabilitation services	Disability awareness, prevention, & education
	Provision of physical rehabilitation services
	Case identification, referral, and follow-up
Regular supply of essential drugs	Listing of all essential drugs needed

Table 2. Expanded Programme on Immunisation activities in Afghanistan by health facility level (MoPH, 2012a)

Interventions and Services Provided	Health Facility Level					
	Health Post	Health Sub-Center	BHC	MHT	CHC	Dist. Hospital
IEC	Yes	Yes	Yes	Yes	Yes	Yes
Storage of vaccines	No	Yes (CB and VC)	Yes	Yes (CB and VC)	Yes	Yes
EPI routine (all antigens)	Yes—support	Yes	Yes	Yes	Yes	Yes
Outreach immunization service	Yes—support	Yes (catchment area)	Yes	Yes	Yes	Yes
EPI-plus (ORS+ De-worming)	Yes—support	Yes	Yes	Yes	Yes	Yes
Supplementary Immunization Activities	Yes—support	Yes	Yes	Yes	Yes	Yes
Disease surveillance and case reporting	Yes	Yes	Yes	Yes	Yes	Yes
VPD outbreak response	Yes	Yes	Yes	Yes	Yes	Yes
Vitamin A supplementation	Yes	Yes	Yes	Yes	Yes	Yes

Health Sub-centers will be linked with their related health facilities for referral and supply/logistics
Health Sub-centers will submit an EPI report to the health facility where they obtain vaccine supplies

Table 3. Routine immunization schedule for Afghanistan (MoPH, 2012a)

Antigen	At Birth	6 weeks	10 weeks	14 weeks	9 months
BCG	X				
Polio	X	X	X	X	X
Pentavalent		X	X	X	
Measles					X

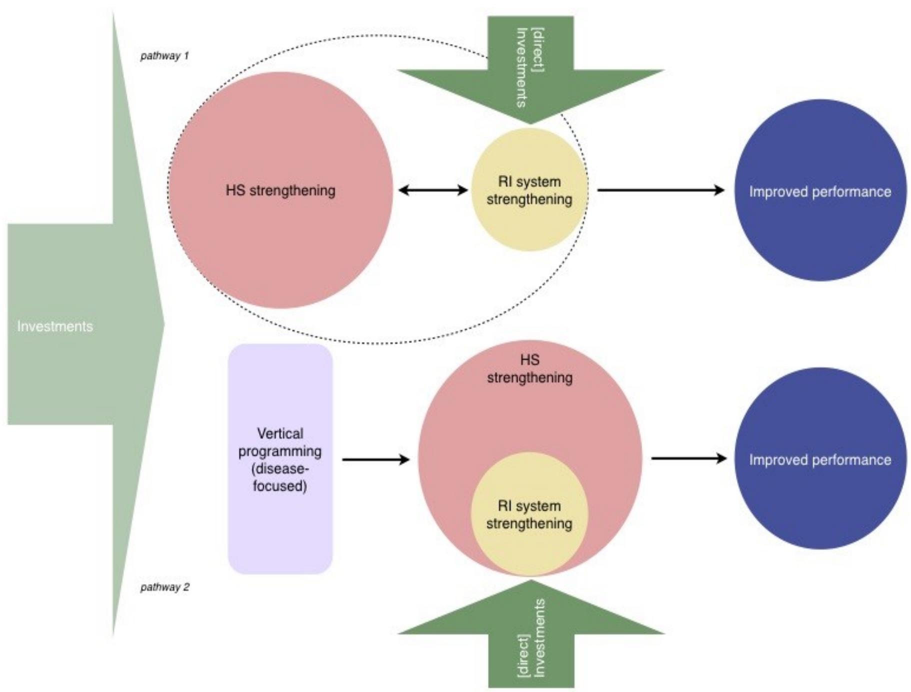
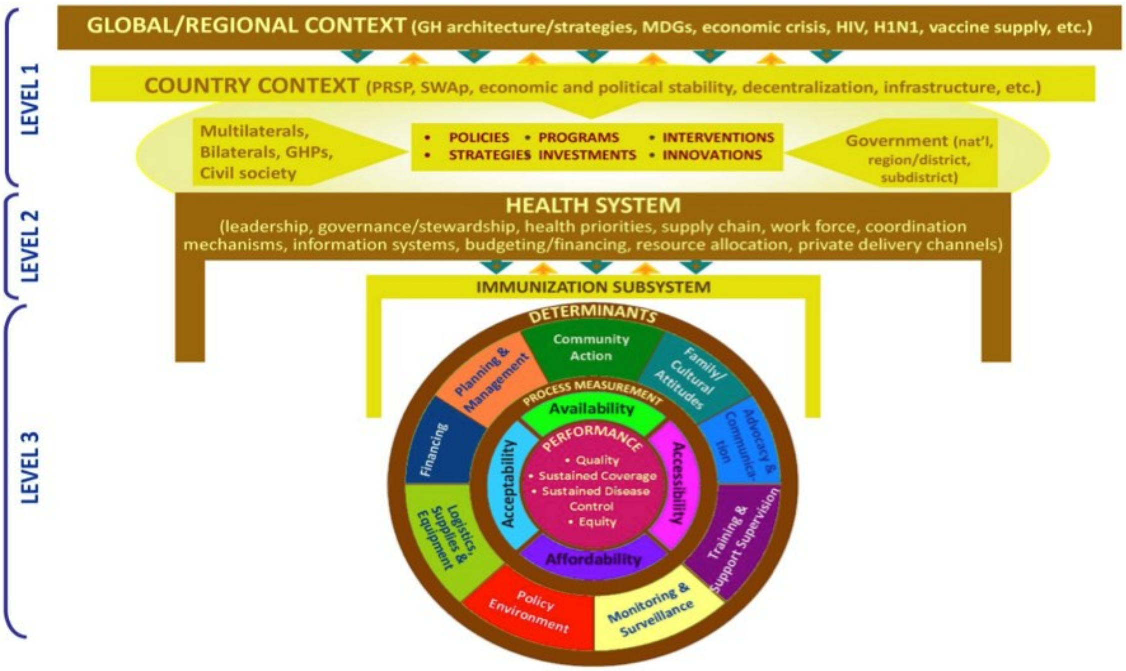


Figure 2. Routine immunization and the health system: two pathways of influence and direct investment theory. Developed based on Steinglass (2013)



Note: GH =global health; MDGs = Millennium Development Goals; PRSP = poverty reduction strategy paper; SWAp = sector-wide approach; GHP = global health partnership

JSI ARISE (2011). Landscape analysis synopsis: an initial investigation of the drivers of RI system performance in Africa.

Figure 3. Routine immunization subsystem: levels and components for improving routine immunization coverage at district level

Intended to be blank.

Chapter 2. Data sources used
2.1 Overview of data sources

2.1.1 Data sources for Paper 1 and 3 (Chapters 3 and 5)

National Health Service Performance Assessment (NHSPA), (2004-13)

Data on service delivery and facility/patient characteristics will come from the 2008-2012 National Health System Performance Assessment (NHSPA), an annual assessment of the BPHS conducted by the Ministry of Public Health (MoPH) with independent technical support (Peters, Noor, Singh, Kakar, & Hansen, 2007). It has been conducted every year since 2004, providing data that allows for the calculation of indicators for overall system performance and patient care that are a part of the implementation of the national BSC. In the case of the Afghan health system, performance across six performance domains (patient and community perspectives, staff perspectives, capacity for service provision, service provision, financial systems, and overall vision) as well as three summary indicators (Edward et al., 2009; Hansen et al., 2008; Peters et al., 2007) comprised the national BSC. Data were collected by an independent team led by the Johns Hopkins Bloomberg School of Public Health (JHSPH) and the Indian Institute of Health Management Research (IIHMR).

Sampling was stratified by the level of the facility where the BPHS is provided allowing for stratified random sampling of 25 facilities within each of 34 provinces in Afghanistan. District hospitals are included in a separate BSC based on the EPHS, a change that since 2009-10 has been implemented. Systematic random sampling was used for the selection of patients, targeting five adults and five children at each facility using a random starting point and a sampling interval determined by the average number of new patients seen daily. Health workers were also selected in a systematic fashion beginning with stratification by three types (i.e. doctors, nurses, and CHWs). Updating a list of health facilities provided by the MoPH created the sampling frame of BPHS health facilities, a process that was carried out by the Provincial Public Health Directors, HMIS officers, and key informants from NGOs and the MoPH in each province. The list of functional facilities was finalized by this group and stratified into the three levels of facilities. Random selection of facilities was carried out according to the following quotas: five Comprehensive Health Centers, fifteen Basic Health Centers, and five Subcenters. The protocol for selection included the provision that if fewer than the specified quota of a particular facility type was available for survey in any province, other facility types were to be substituted.

Due to issues of security or because health infrastructure may have been completely void at the time of the survey, sampling was difficult to achieve in every province year to year. In 2004 Daykundi province was not included because at this time, it was a newly formed province with no BPHS facilities at the time the 2004 NHSPA was conducted. In the years from 2005-2007, the NHSPA included Daykundi but excluded the provinces of Kandahar, Helmand, Zabul, and Uruzgan due to security issues. The 2008 NHSPA was again affected by worsening security and thus was not carried out in Farah, Kandahar, Helmand, Zabul, and Uruzgan provinces. The 2009-10 NHSPA included all 34 provinces whereas the 2011-12 assessment excluded Nuristan due to security-related issues. The 2012-13 NHSPA was conducted in all 34 provinces. A summary of the national sample for NHSPA for each of the eight years during the 2004-2013 period is provided in Table 4 below as taken from the April 2013 BSC report

(Ministry of Public Health et al., 2013). Data come from six combinations of forms as outlined in Table 5.

Afghanistan Household Survey, 2012

Data on household characteristics and service delivery outputs mostly measured in terms of "coverage" will be derived from the 2012 Afghanistan Household Survey (AHS) conducted by teams represented under the same institutions that lead the NHSPA. The survey was designed to collect information on maternal and child health, family planning, child survival, health care utilization, and health-related expenditures in Afghanistan. For data collection, a multi-stage random sampling strategy was used. The sampling frame is based on the 34 provinces of Afghanistan where each province was divided into districts that were then divided into enumeration areas, which were villages and sub-villages in rural areas and blocks in urban areas. The sampling frame, a pre-census household listing, included over 45,000 enumeration units in rural and urban areas that later excluded any abandoned and destroyed villages before sampling was conducted (Afghan Ministry of Public Health, Johns Hopkins Bloomberg School of Public Health, & Indian Institute of Health Management Research, 2012). The survey combined data collected under the Results-Based Financing (RBF) and the Monitoring & Evaluation Technical Assistance to Strengthening Health Activities for the Rural Poor (METASHARP) projects, a strategy to avoid duplication of efforts, avoid wasting resources, and meet a severely condensed project timeline as proposed by donor and steward.

In nine RBF provinces, a multi-stage probability sampling scheme was carried out first by selecting health facilities sampled using a stratified random technique based on facility type. Second, two villages were randomly sampled from the list of all villages within 2-hour walking distance of each selected health facility. Third, using the household listing conducted prior to the survey, the 24 households were sampled in each of the selected villages using simple random sampling. In the remaining 25 METASHARP provinces, a stratified multi-stage cluster sampling approach was used, first by creating a list of all clusters within each province with cumulative population size. Second, clusters were sampled using systematic random sampling in each province. Third, each cluster was subdivided into segments such that each segment had an approximate fixed size of 20 households. Following the steps according to the compact segment approached described by Turner and colleagues (Turner, Magnani, & Shuaib, 1996), one segment was randomly selected and all households within this segment were sampled. Design weights were created and applied to the provincial and national estimates with special care given for creating the national weights to address the difference in probability of selection by province.

Two questionnaires were used including: 1) the Head of Household Questionnaire, and 2) the Female and Child Health Questionnaire. The head of household questionnaire included a household listing and assets and wealth, care-seeking behavior, and health expenditure modules. The Female and Child Health questionnaire included modules on women's pregnancy history, ANC and delivery care, childhood immunization, childhood illness, and patient satisfaction. A total of 552 clusters were completed yielding data from 12,137 households across 33 provinces, including 14,551 women aged 12-49 years and 14,589 children under age 5 years.

National Risk and Vulnerability Assessment, 2007-08

As the third of three successive rounds of the National Risk and Vulnerability Assessment (NRVA) survey, the NRVA 2007-08 was launched jointly by the Ministry of Rural Rehabilitation and Development and the Central Statistics Office with cooperation from the European Commission. The purpose of the survey was to provide governments and other agencies with more robust and up-to-date socio-economic data for Afghanistan (Ministry of Rural Rehabilitation and Development & Office, 2008). The sampling frame comes from the pre-listing of the households that the Central Statistics Office collected in preparation for the national census in 2004, and from this a geographically ordered list of all primary sampling units (i.e. rural settlements and urban blocks) was created. Sampling was carried out proportionally to the population with over-sampling of smaller provinces and urban centers. Sampling was based on random start method for better geographic representation of the sample, and households within selected villages were randomly selected from the Central Statistics Office household listings. Eight households per village were selected for interview. Overall, the survey coverage includes 34 provinces, 395 districts, 2,572 clusters, 20,576 households, and a total of 152,262 individuals.

Two questionnaires were used: one for household data collection and the other for shura data collection. Each questionnaire was divided into male- and female-appropriate questions that were asked of and answered by the respective gender (out of 20 sections, 14 were answered by the male head of households or male respondent while the women's portion included the remaining six sections).

2.1.2 Data sources for Paper 2 (Chapter 4)

For Causal Loop Diagram development

A rapid, non-exhaustive literature review on the *readiness to deliver immunization services* in low- and middle-income countries (especially in fragile states) and immunization system structure was conducted in PubMed, Scopus, and Embase using combinations of key terms such as ‘immunization’, ‘vaccination’, ‘immunization programs, ‘delivery of health care, ‘health services, ‘systems analysis’, and ‘maternal health services’. We included articles and reports from previous work on immunization services and programs. Findings on immunization program components, structure, and linkages to the health system and its performance were most useful. Immunization system components were further categorized and supported by context-, content-, and methodology-knowledge (Afghanistan, immunization programs in low- and middle-income countries, health service delivery, systems thinking and modeling). Initial lists of subsystem-system components and definitions of relationships were created. These lists were refined based on the triangulation of the data from the different sources including empirical findings from a secondary data analysis (Chapter 3). Themes were identified emerging from common domains of service delivery (Edward et al., 2011; Peters et al., 2007; WHO, 2007) in health systems and within immunization systems (e.g. supply chain (cold chain) capacity, stock and inventory of supplies at different levels of the system/subsystem, human resources for delivering services (vaccination), surveillance (lab) capacity for case confirmation, demand capacity).

For model validation and finalization

A validation process was carried out, soliciting feedback from methods, context, and content experts. This process was approved by the Institutional Review Board (IRB) at the Johns Hopkins Bloomberg School of Public Health and deemed non-human subjects research. An initial group of thirteen experts were identified for their expertise in immunization and immunization programs, health service delivery systems and tradeoffs, immunization and health policy, or Afghanistan or developing country contexts of any of these content areas. Experts had backgrounds in immunization policy development, immunization program monitoring and evaluation, country-level immunization program management (in developing countries), technical support to national immunization programs in the areas of surveillance, community engagement, and program management, community engagement and communication for immunization in developing countries, medical practice and research in Afghanistan, and local knowledge of Afghanistan. They represented private and public organizations, government and multi-lateral organizations, academic institutions, and local Afghan organizations and government. These experts were asked to review and provide feedback on the CLDs.

2.2 Chapter 2 Tables and Figures

Table 4. National samples for the National Health System Performance Assessments, 2004-2013 (MoPH, 2013)

UNIT	2004	2005	2006	2007	2008	2009-10	2011-12	2012-13
Number of Provinces	33	30	30	30	29	34	33	34
Number of Facilities	617	629	630	636	618	726	738	725
Number of Observations of Patient-Provider Interactions	5719	5856	5964	6089	5970	7979	6826	6930
Number of Exit Interviews	5597	5862	5964	6087	5950	7979	6826	6930
Number of Health Workers Interviewed	1553	1452	1723	1940	2233	2281	2393	2403

Table 5. National Health System Performance Assessment data collection forms

Name of form	Description
F1 / F3	Patient observation / Exit interview (under 5 years of age)
F2 / F4	Patient observation / Exit interview (>=5 years of age)
F5	Health worker interview
F6	Community health worker (CHW) assessment
F7	Facility assessment (BHCs, CHCs, SHCs)
F8	Facility assessment (HPs)

Intended to be blank.

Chapter 3. Examining the association between health system readiness to deliver immunization-related services over time and immunization coverage in Afghanistan: an ecological study using regression tools to explore health subsystem readiness and performance (Paper 1)

Abstract

Background. This ecological study aimed to examine the association between *system readiness to deliver immunization services* and *immunization coverage outcomes*.

Methods. Four years of facility-based data (2007-08 through 2012-13) from the National Health Service Performance Assessments in Afghanistan were combined with two cross-sectional sets of population data (household) from the 2007-08 National Risk and Vulnerability Assessment and 2012-13 Afghanistan Health Survey. Provincial-level indicators of health system readiness to deliver immunization services were developed and included as predictors in marginal, generalized linear models. The outcome of interest was 2012-13 provincial-level coverage (proportion) of the third dose of Pentavalent vaccine received among 12-13-month-old children. The baseline measure of the immunization coverage was a covariate in the models. Other contextual factors were calculated for the 2012-13 Pentavalent coverage using household data and included in the models.

Results. Wealth-adjusted models were created that adjust for the distribution of household wealth groups separately (poorest, middle-income, and richest). Average vaccine stock readiness in provinces was associated with the largest change in immunization coverage among all readiness factors (10-percentage point increase in stock scores associated with 3.92 (95% CI: 0.17, 7.66) to 5.19 (95% CI: 1.37, 9.01) percentage-point increase in immunization coverage). A 10-percentage point increase in the proportion of women who exclusive breastfed their last child was associated with 2.18 (95% CI: 0.62, 3.74) to 3.44 (95% CI: 2.09, 4.78) percentage-point increase in immunization coverage. Demand-side factors such as proportion of households living

within two hours of nearest health facility and women's educational status were marginally statistically significant in models adjusting for middle-income households (e.g. 1.61 (-0.04, 3.25) and 4.29 (1.23, 7.34) percentage-point increase in immunization coverage for a ten-point increase, respectively). Depending on the household wealth group, an increase of ten points in the distribution of a wealth status group was associated with negative and positive changes in immunization coverage (for poorest: -1.76 (-2.88, -0.63); for middle-income: 2.92 (1.72, 4.12)).

Conclusion. Based on the non-causal associations found in this study, the main issue concerning readiness for vaccination services appears to be the ability to assure vaccines are readily available at health facilities. Basic laboratory capacity may indicate overall capacity of health facilities that supports vaccination service delivery. Women's health behaviors pattern similarly to immunization coverage, which may indicate the key role that mothers play in childhood immunization performance as primary care givers.

3.1 Background

There are a limited number of examples of the use of quantitative methods for measuring the relationship between intervention-specific strategies and health system performance. The idea of routine immunization as a sub-system is emerging in the literature (Clements et al., 2011; JSI, 2011; Steinglass, 2013; S A Wang et al., 2013). Strengthening the routine immunization sub-system may mutually reinforce the health system or cause distortion, and similarly strengthening the HS may directly influence the national immunization program in a positive way or preclude measureable impact. Regardless of the direction from which we approach the routine immunization – health system relationship, tradeoffs may exist.

Readiness of a health system to deliver health services and products is the primary focus of program development. In immunization policy, the 2011-2020 Global Vaccine Action Plan (WHO, 2011b) consists mainly of supply-side objectives: Five of the six focus primarily on national immunization programs' service-side readiness to deliver vaccines and vaccination services, comprehensively setting expectations for inputs and processes for building immunization system capacity and readiness to develop, assure quality of, store, and manage the movement of vaccines. *Readiness* consists of the necessary components to ensure that immunization services can be provided in a country program. These may have been parsed into domains of health system performance in the Balanced Score Card (Edward et al., 2011; Peters et al., 2007) or the six block health systems framework by the World Health Organization (van Olmen et al., 2012; WHO, 2007). More comprehensively, system readiness to deliver immunization services includes components as presented in the JSI framework (JSI, 2011) for improving immunization coverage (Figure 3).

According to Gauri and Khaleghian (Gauri & Khaleghian, 2002), immunization strategies have notable characteristics that make them different from other health strategies. The authors described a stronger consensus among technical experts in the field, a shorter time-frame for policy and program reform, weaker household demand compared to curative care, and weaker support from providers in comparison to other areas of health reform such as provider payment and risk-pooling schemes (Gauri & Khaleghian, 2002). As children continue to be born, immunization-related activities, especially those encompassing routine activities, will remain a necessary investment for health systems worldwide. Focus has been given to temporary, exhaustive eradication efforts (e.g. Polio Eradication and Measles Eradication Initiatives) while the public image for systems such as those for routine immunization suffers (Steinglass, 2013). Immunization programs are heterogeneous in design and require commitment to both episodic and routine interventions.

Monitoring and evaluation on vaccination uptake have been defined in terms of two indicators: coverage and/or timeliness (Bosch-Capblanch et al., 2012). Typically, coverage alone has been used to define the progress of routine immunization because of the ease of capturing the measures needed to estimate coverage. Coverage is defined as "the proportion of targeted children who have received vaccines". Measurements of coverage of multiple doses for the same vaccine (e.g. DTP3) and dropout rates help to describe the ability of the system to deliver multiple-dose vaccines (Bosch-Capblanch et al., 2012). DTP3 (or its equivalent, pentavalent) coverage is often used as an routine immunization coverage indicator mainly because it is delivered only in routine immunization activities and it indicates system capacity to engage infants in three consecutive vaccination events (Bosch-Capblanch et al., 2012; Duclos et al., 2009; Lim et al., 2008; Shearer et al., 2012). Measles coverage has been used with DTP3 coverage to measure the strength of routine immunization (Steinglass, 2013). Additional aggregate measures that include fully-immunized children (all vaccines under the vaccination schedule given on time) and partially-immunized children have been used to describe in-country routine immunization status.

This study aims to examine the relationship between <u>readiness of the health system to deliver immunization-related services</u> and <u>immunization outcome performance (coverage)</u> at the provincial level in Afghanistan as a first step in examining the role of the immunization system in the broader health system in this thesis research (Figure 4)**.**

3.2 Methods

This study linked household survey data to annual health facility assessment data. These data were collected during the annual National Health Service Performance Assessment (NHSPA) in Afghanistan from 2007-2012 and during two household surveys in Afghanistan during 2007 and 2012 (the National Risk and Vulnerability Assessment (NRVA) and the Afghanistan Household Survey (AHS), respectively). The Institutional Review Board at Johns Hopkins School of Public Health and the MoPH Ethical Review Board in Afghanistan approved these studies.

NHSPA data: The five years of NHSPA (facility) data were collected from 29 provinces of Afghanistan. These measures served as the basis for independent variable identification (service-side readiness measures) in this study. Methods for instrument design and the health facility sampling scheme are described elsewhere (Hansen et al., 2008; Peters et al., 2007). Facilities delivering the Afghan BPHS were considered eligible, and stratified sampling by level of facility was used to select 25 facilities in each of 34 provinces each year. The samples were the same from 2008-2009 and from 2009-2012, where 3 district hospitals, 7 comprehensive health centers, and 15 basic health centers as well as 5 comprehensive health centers, 15 basic health centers, and 5 subcenters were sampled, respectively. District hospitals are included in a separate BSC based on the Essential Package of Health Services (EPHS), a change that since 2009-10 has been implemented. Further changes between 2007-2008 and 2009-2012 periods are published elsewhere (Edward et al., 2011). For this analysis, data are from facility assessments conducted in basic health centers, comprehensive health centers, and subcenters. A total of 2747 health facilities were included in the final dataset for analysis (Table 6).

We constructed the following immunization service readiness variables for health facilities: a vaccine stock (including expired inventory), cold chain storage and transport functionality, number of health workers who provide vaccination services, health workers who have had vaccine-specific refresher training, management agency type, precautions universal precautions capacity, management reminders (i.e. immunization schedule and IMCI chart are present), and laboratory capacity for vaccine-related diagnostics and surveillance. Mean scores were constructed for laboratory, stock, precautions, management, and cold chain readiness at facilities (see Appendix I, Table 18). An index was constructed using a mean score of multiple items for each area of readiness at facilities for each province across each year. An item was rated as 1 if it was available or in good condition or as 0 otherwise. Scores ranged from 0 to 100 and were averaged for each province and year combination. Basic laboratory capacity at health facilities was assessed by the ability to conduct the following tests: tuberculosis (TB) smears, malaria smears, rapid malaria, liver function, hepatitis B, and gram. Vaccine stock at facilities was assessed by an inventory (present and viable, present and expired, etc.) of the following vaccines: Bacillus Calmette-Guérin vaccine for TB; oral polio vaccine (OPV) for polio; pentavalent vaccine (PENTA) for diphtheria, pertussis, tetanus, hepatitis B, and Haemophilus influenza type B (Hib); measles vaccine; and tetanus toxoid vaccine. Cold chain functionality was determined based on storage and transportation components inventoried at each facility such as a refrigerator, ice/transfer box, power source, temperature log, etc.

NRVA data: One year of NRVA data (the third successive round of this survey) were collected in the same 29 provinces where the NHSPA was administered. Sampling was proportional to the population (based on the sampling frame from the pre-census listing of the households conducted in 2004 by the CSO in Afghanistan with over-sampling of smaller provinces and urban centers (Ministry of Rural Rehabilitation and Development & Office, 2008). It was based on a random start method for better geographic representation of the sample. Households within selected villages were randomly selected from CSO household listings. Eight households per village were selected for interview. Overall, the survey coverage included 34 provinces, 2,572 clusters, 20,576 households, and a total of 152,262 individuals (Table 7). Provincial-level immunization coverage estimates were gleaned from these data. Further description of

NRVA 2007-08 methods can be found elsewhere (Ministry of Rural Rehabilitation and Development & Office, 2008).

AHS *data*: One year of AHS data were collected in the same 29 provinces where the NHSPA was administered. We used a multi-stage random sampling strategy based on the subdivision of the 34 Afghan provinces into districts and then further into enumeration areas (villages and sub-villages in rural areas and blocks in urban areas). The sampling frame was based on the updated version of the same sampling frame used for the NRVA 2007-08 survey (Ministry of Rural Rehabilitation and Development & Office, 2008). Overall, the survey coverage included 33 provinces, 552 clusters, and a total of 12,137 households (Table 7). Provincial-level immunization coverage estimates, household characteristics, and environmental characteristics were gleaned from these data. The study methods are further described in the final report of the AHS, conducted in 2012 (Afghan MoPH et al., 2012). Coverage estimates were calculated by taking the number of eligible persons who received the given health service divided by the number of total eligible persons. Household wealth quintiles were created using principal component analysis PCA) to ascertain one component from 22 household assets variables (Jolliffe, 2002). More details on household assets that made up the wealth quintile scores can be found in Appendix II (Table 19). Quintiles were created into three distributions of wealth variables: poorest households, middle-income households, and richest households.

Data quality control was assured through use of standard in-field procedures and double data entry and consistency checks (Edward et al., 2009). To identify the characteristics of service-side readiness that affect immunization coverage performance, we used bivariate and multivariate analysis of patient, provider, facility, household, and environmental-related factors known to affect the immunization coverage of the third dose of Pentavalent vaccine (PENTA3). Initially, we used bivariate analysis to examine the pattern of responses and extent of missing values to construct any combination mean scores of service-side readiness. Missing values (<5%) were omitted from the analysis and deemed as missing at random (MAR). Missing values (>5%) were assessed for missing at random. An iterative form of stochastic imputation, multiple imputation, was used where MAR was determined (Rubin, 1987). Data collection was limited in the provinces of Badghis, Kandahar, Daykundi, Nuristan, Zabul, Helmand, and Farah provinces due to low security during each of the years of NHSPA, AHS, and NRVA data collection.

Province was used as the level of analysis; exposures and PENTA3 coverage estimates were summarized at the provincial level. All analyses were carried out in Stata 12 (Stata Corp LLC, 2011). We used bivariate analysis to compare differences in immunization coverage between 2008 and 2012. Combinations of selected exposure variables were examined using bivariate analysis, and potential confounders were tested by comparing beta coefficients of regression models that included only the predictor of interest and those of regression models with multiple covariates of interest. Backward step-wise regression was used to consider suggested covariates based on a significance level of 0.20. Effect modification, spline covariates, and covariates were tested using likelihood ratio tests between full and partial models. We determined final model covariates based on pre-analytical conceptualization of relationships among the key outcome, key exposures, confounders, and effect modifiers as well as the described analysis.

We used generalized linear models (GLM) models (McCullagh & Nelder, 1983) specifying the family as binomial with a logit link due to the nature of the outcome of interest (bounded by 0, 1 as a proportion with few/no 0 or 1 values). Though these were panel data from combined survey data, data did not include provincial-level coverage estimates for each of the given years. Instead provincial-level coverage estimates were calculated using two cross-sectional studies conducted during the first year of data collection for calculating *readiness predictors* (mid-2007 to mid-2008) and the last year of data collection for calculating *readiness predictors* (mid-2012 to beginning-of-2013). These two sets of cross-sectional, population-based estimates were calculated from the only available data that could give provincial-level representative coverage estimates while also matching the time steps of health facility assessments. Provincial-level coverage estimates limited need for accounting for clustering at the facility-, health worker-, or household-levels, but NHSPA-based covariates were still time oriented. To improve standard errors and account for clustering by time, we used a Huber-White (robust) sandwich estimator for estimating the variance. We used the variance inflation factor (vif) as well as .collin command in Stata and accompanying tests to assess multi-collinearity. Influential and leveraging observations were examined for their effect on modeling output. Model fitness was further examined using graphical plots of residuals and fitted values as well as Akaike information criterion (AIC) comparisons (Deroche, 2015; McCullagh & Nelder, 1983).

3.3 Results

Two readiness variables (*cold chain capacity mean score* and *average number of vaccinators at a facility*) were excluded from the final model. Neither was found to be a significant predictor in the model. The cold chain capacity score was found to have no confounding effects on the covariates. The vaccinator count variable had a high vif value and was closely correlated with vaccine-specific training exposure. Average counts of nurses, midlevel health workers, vaccinators, general physicians, and physicians with specialization in obstetrics and gynecology (obgyns) were tested for significance. Only the obgyns count was a statistically significant predictor of Penta3 coverage using bivariate analyses but they represented 3-6% of the health worker population counted at facilities. The other health worker counts were carried forward into generalized linear models to examine any confounding effects. The exposure for vaccinator counts was closely correlated and collinear with the exposure of health worker receipt of refresher vaccine-specific training.

We kept the following variables indicating readiness to deliver vaccination services (readiness variables) in the final model:

- Basic facility laboratory capacity score
- Facility vaccine stock score
- Vaccine-specific refresher training of health workers

We also included the following contextual factors in the model:

- Household wealth status
- Household travel time is less than two hours to the nearest health facility (when a household member has reported illness in the past two weeks)
- Educational status (if a woman has ever attended school formally)
- Time (NHSPA year)
- Exclusive breastfeeding practices
- Whether women who know of local CHWs agree that CHWs provide a useful service to their community
- Second dose of tetanus toxoid during pregnancy (TT2)
- Past coverage of the third dose of pentavalent vaccine among 12-23-month-old children (Penta3)

We found multicollinearity among the proportion of household wealth statuses in each province. Change in beta coefficients were observed for assessing confounding effects. Education acted as a confounder on the relationship between the outcome and the proportion of households living within two hours to the nearest health facility and household wealth status distributions in provinces. Education also confounded the relationship between the outcome and the distributions of vaccination re-trained health workers. This pattern was the same when controlling for the distributions of poorest, middle, richest, and both poorest and middle households together in provinces. we tried to avoid multicollinearity by presenting four different separate models that control for different proportions of household wealth. They are: poorest-, both poorest- and middle-, middle-, and richest- household models.

Four wealth-adjusted models were developed (controlling for poorest, poorest and middle-income, middle-income, and richest households). In the poorest households-adjusted model, an increase in the average vaccine stock readiness score by ten percentage-points was associated with about a 4.34 (95% CI: 0.57, 8.11) percentage-point increase in immunization coverage (Table 8). This effect was similar for the middle-income, poorest and middle-income, and richest household adjusted models (3.89 (95% CI: 0.16, 7.63), 3.92 (95% CI: 0.17, 7.66), and 5.19 (95% CI: 1.37, 9.01) percentage-point increases, respectively) (Tables 9-12).

Also in the model controlling for the distribution of poorest households, an increase in the average basic laboratory readiness score by 10% was associated with about a 1.65 (95% CI: 0.18, 3.12) percentage-point increase in immunization coverage, and this association as statistically significant (Table 8). Similar effects were observed for the association between 10-percentage-point increases in the average basic laboratory readiness scores and immunization coverage in the models adjusting for middle-income, poorest and middle-income, and richest household distributions (1.52 (95% CI: 0.11, 2.93), 1.51 (95% CI: 0.09, 2.93), and 1.62 (95% CI: 0.02, 3.22) percentage-point increases, respectively) (Tables 9-12).

Women's health behaviors such as exclusive breastfeeding practice and the receipt of at least two doses of the tetanus toxoid vaccine during pregnancy were statistically significantly associated with immunization coverage (a 10-percentage-point increase in either was associated with a 3.44 (95% CI: 2.09, 4.78) and 3.00 (0.37, 5.64) percentage-point increase in immunization coverage, respectively) (Table 8). While the tetanus toxoid vaccination covariate did not remain statistically significant in the other wealth distribution-adjusted models, a 10-percentage-point increase in the proportion of women with exclusive breastfeeding practices was associated with 2.98 (95% CI: 1.93, 4.03), 2.85 (95% CI: 1.28, 4.43), and 2.18 (95% CI: 0.62, 3.74) percentage-point increases in immunization coverage in the middle-income, poorest and middle-income, and richest household adjusted models (Tables 9-12).

The wealth status variables, representing distributions of households categorized by wealth status, were found to be statistically significantly associated with immunization coverage in three of the four wealth-adjusted models. A 10-percentage-point increase in the proportion of poorest households and middle-income households (in the poorest and middle-income model and in the middle-income model) was associated with a change of -1.76 (95% CI: -2.88, -0.63), 3.20 (95% CI: 1.06, 5.35), and 2.92 (95% CI: 1.72, 4.12) percentage-points in immunization coverage, respectively (Tables 8-12).

Women's educational status was found to be statistically significant in the models controlling to middle-income household distributions as well as both poorest and middle-income household distributions (ten percentage-point increase in the proportion of women having been formally enrolled in school is associated with 4.29 (95% CI: 1.23, 7.34) and 4.98 (95% CI: -0.16, 10.13) percentage-point increases in immunization coverage). Ten percentage-point increases in the proportion of households living within two-hours traveling distance to the nearest health facility were also marginally statistically significant in the middle-income model as well as the poorest and middle-income model (1.61 (95% CI: -0.04, 3.25) and 1.74 (95% CI: -0.02, 3.50) percentage-point increases in immunization coverage).

3.4 Discussion

Both systems readiness factors and demand-side factors were associated with Penta3 coverage. Among the covariates that were persistently significant (including past immunization coverage), two we would describe as system readiness related (i.e. vaccine-specific stock readiness and vaccine-related laboratory capacity). Demand-side factors that may describe patterns of household health behaviors show such as exclusive breastfeeding practices and second dose of tetanus toxoid during pregnancy remained statistically significant in each of the wealth-specific models. Improvements in wealth, education, and traveling distance to the nearest health facility would suggest greater gains in immunization coverage when controlling for middle-income households compared to gains gained when controlling for the poorest and richest household groups.

3.4.1 Vaccine-specific readiness variables: Vaccine stock and basic laboratory capacity

Our findings suggest that laboratory capacity for vaccine-related testing as well as vaccine stock availability are two of the more influential immunization service-delivery readiness factors that affect Penta3 coverage in provinces in Afghanistan. Throughout the analysis, these two time-varying components persistently maintained a statistically significant association with the current Penta3 coverage. As one of these, the vaccine stock at facilities is a necessity for providing vaccination. In cases where stock-outs have been recorded or experienced by patients, we may not know the effect (or behavioral effect) that stock-outs have on health workers and patients. Having an adequate supply of vaccine stock at facilities ensures not only that vaccination events occur when patients visit the facility but also that future vaccination events are not adversely affected by the public's view and possible generalization of vaccine availability (Mvula, Heinsbroek, Chihana, Crampin, Kabuluzi, et al., 2016; Suarez-Castan(Burchett et al., 2014; Favin et al., 2012; Mounier-Jack, Griffiths, Closser, Burchett, & Marchal, 2014; Suarez-castaneda et al., 2015).

The other exposure is basic, vaccine-related laboratory capacity at health facilities that report having a laboratory. It was steadily significant throughout the analysis and consistently presented as a slightly weaker exposure compared to vaccine stock. Limited laboratory diagnostic capacity was listed as a common weakness for all countries that were a part of the Service Availability and Readiness Assessment, a tool used to monitor supply of health services at facility level for determining universal coverage of health care (O'Neill, Takane, Sheffel, and Boerma, 2013). Critical for functioning infectious disease surveillance systems, laboratory capacity in our analysis may indicate the overall capacity (i.e. more resource availability, more complex care facility) linked to the size and type of facility. Most of the facilities that have the components of the laboratory readiness score are comprehensive health centers but some measures do come from the basic health centers.

3.4.2 Cold chain measures and its relationship to stock measures

Though we had an expectation that cold chain capacity measures would be associated with vaccination coverage, the covariate for cold chain capacity at health facilities was dropped before reaching the final model of the analysis. A cold chain (supply chain) encompasses the series of steps required to get vaccines from manufacturers to patients. We used items like those captured in an EPI health facility capacity assessment (Ateudjieu, Kenfack, Nkontchou, & Demanou, 2013), resulting in a cold chain score focused on storage and transfer capacity at health facility (i.e. presence of a refrigerator for vaccine storage, if the refrigerator works or there is a functioning power source or a temperature log is kept, etc.). It may be that defining cold chain functionality by proximal characteristics at a facility rather than the distal characteristics that are precedent is less meaningful for coverage than a comprehensive cold chain measure or that the proximal characteristics are important for stock quality measures at the facility. The limited correlation may also be due to time effects where the cold chain, over time, became more capable and reached a threshold level for capacity after which its effect cannot be seen on current vaccination coverage estimates. It may have a detectable effect on coverage estimates over time. Overall, there was very little variability in our cold chain scores where they ranged from about 80 to 100%.

Stock, or inventory, could be generally described as a result or outcome of a functioning cold chain, similar to the research question addressed by this study (inputs and processes of system readiness contributing to coverage outcomes). As a measure of vaccine availability, a stock or inventory measure of vaccines can easily be obtained whereas the performance of a supply chain includes some measures obtained at facilities but also requires operational measurements accounting for the processes and infrastructure supporting the movement of vaccines from country level down to regional, provincial, facility, and even community level (as in the case of vaccination outreach and service extension efforts). Similar to our preliminary findings on cold chain capacity, health facilities had sufficient capacity for storage and transport capacity according to an effective vaccine management assessment conducted by the Ministry of Health and WHO staff (WHO, 2011a). In that assessment, temperature monitoring, maintenance, stock management, and storage and transport capacity at higher levels of the system did not perform as well. Our data are limited to laboratory capacity at health facilities as an inventory of storage and do not include higher levels, which may contribute to the consistent lack of statistical significance of the cold chain covariate.

3.4.3 Demand-side predictors

Consumer-/community-related characteristics such as income, education, and maternal health service coverage estimates (which help understand household health seeking patterns) were statistically significant predictors. In our analysis, maternal education was found to be associated with immunization coverage only in the models adjusting for middle-income household distributions in the provinces. Maternal education and knowledge have been shown to positively influence use of routine immunization services (Maekawa et al., 2007; Sanou et al., 2009) as well as level of both parents' education and how it may correlate with their knowledge of vaccines (Bosch-Capblanch et al., 2012; Sanou et al., 2009). While proximity to the nearest health facility was not a consistent, statistically significant predictor in our analysis, location of residence related to proximity to health facilities (Chan Soeung et al., 2013; Gauri & Khaleghian, 2002; Hemat et al., 2009) has been found to affect vaccination coverage. One known article examines factors associated with routine immunization coverage in the context of Afghanistan (Hemat et al., 2009). Similar to our findings, this study provides evidence on the role of context- or community-specific predictors (e.g. discontinuity in service provision, facility-based deliveries, use of ANC services, proximity to nearest health facility sites providing vaccines, and the amount of contact with outreach activities in rural areas of the country) on Penta3 coverage in addition to service delivery readiness.

The trend for household wealth status shows that as we control for the distribution of household wealth groups increasingly (poorest, poorest and middle, middle, and richest), the effect of income changes from being negatively associated with immunization coverage (as the distribution of the given household wealth status increases, immunization coverages declines) to being positively associated with immunization coverage (as the distribution of the given household wealth status increases, immunization increases). When accounting for middle-income households, an increase in the distribution of educated mothers was associated with a significant increase in immunization coverage. In the poorest, poorest and middle, and middle-income models, exclusive breastfeeding remained statistically significant only in the model adjusting for the distribution of poorest households while the effect of education dropped. It may be that when controlling for low-income households, mothers' health seeking behaviors contribute more to improved immunization than education does. Mothers' health seeking behaviors have been found to be patterned in Afghanistan with previous health seeking contributing to future health seeking (Tappis, Koblinsky, Doocy, Warren, & Peters, 2016).

3.4.4 Study limitations

Because data were not available for corresponding years of the NHSPA, only two time points of service coverage information were available. Two methods were considered for modeling the coverage outcome: percent change calculated using 2012-13 and 2007-08 outcome data using regression models and secondly controlling for the 2007-08 baseline measure as a covariate in generalized linear models where 2012-13 Penta3 coverage (as a proportion, 0-1) was modeled using a logit link and assuming a binomial distribution. There are some suggested limitations to modeling percentage change (Vickers, 2001). The use of percentage change from baseline as an outcome in a controlled trial has been found to be statistically inefficient (Vickers, 2001).

Interpretation of findings should take the ecological study design into consideration. Findings represent non-causal associations of ecological-level covariates and immunization coverage. Heterogeneity of covariate levels may exist within the study groups, making findings prone to an ecologic bias. Moreover, control for confounding effects is more problematic in ecological analyses than in individual-level analyses (Rothman, Lash, & Greenland, 2008). This was difficult because of the limitations in merging data collected at facilities with those collected in households. Temporal ambiguity is also a concern related to ecologic studies, and it is possible that latent periods between exposure and outcome exist (e.g. vaccine stock availability impacting future immunization coverage). For relationships in health systems, it is difficult to determine systems-level effects and whether a new intervention or policy was fully implemented. Because the analyses included provincial-level context exposures, it is unclear whether living in a region that, for example, has high tetanus toxoid vaccination coverage affects a woman's decision to have her child vaccinated or whether a different exposure at a facility, household, or individual level is more influential.

Sampling methods as well as the data collection tools for the NHSPA changed in 2009, which may contribute to information bias. By limiting covariates to those that can be traced back through the years, assessing for patterns in missingness associated with time, and controlling for year-to-year time steps of the NHSPA in the models, we tried to limit the effects of the sampling and tool changes. There were limitations due to the availability of data for creating process- and output-oriented readiness measures (e.g. cold chain, stock, etc.). It may be more important to measure processes to determine the performance of cold chain whereas the simple yes/no inventory is appropriate for stock; therefore, vaccine stock was used as a proxy for the efficiency and effectiveness of the immunization logistics system.

We did not have stable measures for security. Moreover, we dropped 6-7 provinces of data for each year of NHSPA data due to sampling limited by insecurity. Thus, the analysis presented in this paper is mostly limited to "secure" areas of the country that are at least known to locals and Afghan-context experts as "relatively safe".

3.5 Conclusion

This ecological study offers a first glimpse at examining country-wide system readiness for delivering immunization services and immunization performance. Though vaccine stock readiness and basic laboratory readiness scores were the main two readiness factors associated with immunization coverage, causation and mechanisms that link readiness to coverage performance are not clear. Further helpful information for modeling system readiness for vaccination services may include community-focused vaccination activities and process- or operations-focused measures within and beyond the immunization system such as operations of the cold chain, community outreach (vaccination service extension and adaptability to improve serve availability), and health worker training.

3.6 Recommendations

This study provides non-causal associations between immunization coverage and system readiness as well as contextual factors. Lower-level analyses would be helpful for examining causal mechanisms and heterogeneity of readiness characteristics within provinces in the immunization system. Specific to Afghanistan, findings from this study suggest the importance of examining health workers and their role in immunization system readiness in Afghanistan as well as exploring pathways that may link laboratory and surveillance capacity to immunization outcomes on a scale lower than provincial-level. While education and household wealth status emerge as factors associated with immunization coverage in literature and in this study, their role in women's health decisions and behaviors is unclear and requires more examination. The immunization system in Afghanistan is likely adaptive to the changing environment, which is reflective of the idea that structure drives human behavior from behavioral economics.

3.7 Chapter 3 Tables and Figures

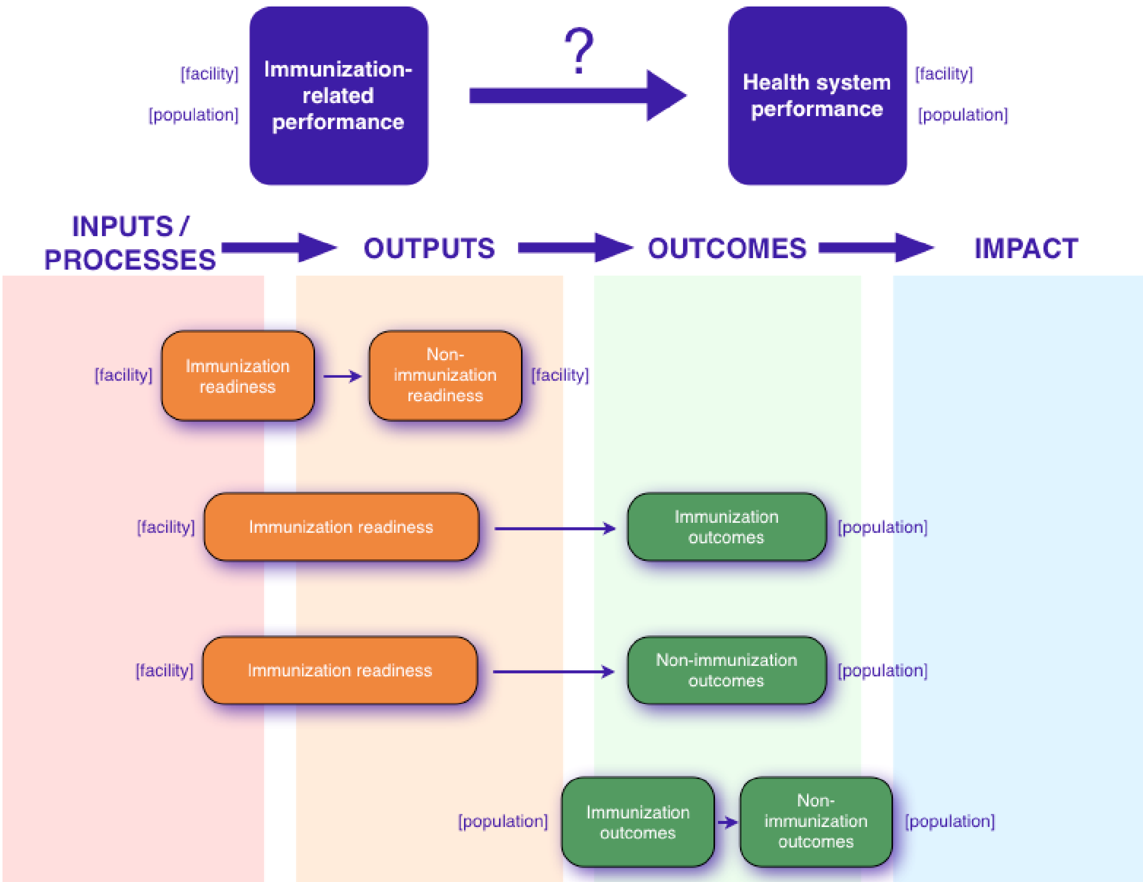


Figure 4. Adapting the World Health Organization health systems strengthening framework to present potential relationships for studying the relationship between the immunization system and the health system (Boerma et al., 2009)

Table 6. Sample sizes for the National Health System Performance Assessments, four consecutive years from 2008-09 to 2012-13

Unit	2008-09	2009-10	2011-12	2012-13
Provinces	28	34	33	34
Health facilities (from reports and data)	558*	726	738	725
Basic Health Centers	372 (62.0%)	403 (55.5%)	413 (56.0%)	370 (51.0%)
Comprehensive Health Centers	186 (31.0%)	181 (24.9%)	170 (23.0%)	182 (25.1%)
Sub centers	0	142 (19.6%)	155 (21.0%)	173 (23.9%)

* 42 district hospitals dropped

Table 7. Sample sizes for the National Risk and Vulnerability Assessment (2007-08) and the Afghanistan Health Survey (2012-13), two cross-sectional, population-based assessments

Units	2007-08	2012-13
Provinces*	34	33
Clusters	2572	563
Household interviews, completed	20576	12209
Eligible women, completed interview	22598	14551
Eligible women per household	1.10	1.19
12-23 month old children, completed	4543	2556
Eligible 12-23 month old children per household	0.22	0.21

* Uruzgon missing from 2012-13 data due to poor security issues

Table 8. Marginal change (dy/dx, 95% confidence interval) in the third dose of pentavalent coverage for each 10-percentage point change in covariate (unless otherwise specified) for associated covariates ($p<0.05$ and $p<0.10$) while controlling for the proportion of poorest households in a province

Exposure	**Percentage point change (dy/dx)**	**P-value**	**95% CI, (LL)**	**95% CI, (UL)**
PENTA coverage (provincial) in 2007-08	2.619	<0.0001*	1.748	3.490
2009-10 versus 2008-09	2.360	0.488	-4.306	9.026
2011-12 versus 2008-09	2.894	0.479	-5.118	10.905
2012-13 versus 2008-09	1.859	0.624	-5.566	9.284
Proportion of households that are in the *poorest* wealth quintile	-1.755	0.002*	-2.881	-0.628
Proportion of households (who had at least one sick member of the household in the past two weeks) that are less than 2 hours from the nearest health facility	0.497	0.548	-1.123	2.116
Proportion of ever-married women ages 12-49 years who have ever attended school	-0.982	0.554	-4.232	2.269
Proportion of ever-married women ages 12-49 years who have had a live birth delivery and the child is still living who exclusively breastfed	3.436	<0.0001*	2.089	4.783
Proportion of women who had a healthy delivery outcome in the past 2 years who received their first and second doses of the tetanus toxoid vaccine during pregnancy	3.004	0.026*	0.366	5.642
Proportion of ever-married women ages 12-49 who are aware of community health workers (CHWs) and who agree/strongly agree that CHWs provide useful services	0.504	0.260	-0.373	1.381
Average vaccine-specific lab score	1.645	0.028*	0.176	3.115
Average vaccine-specific stock score	4.341	0.024*	0.571	8.112
Proportion of health workers who have received vaccine-specific training in the past six months (or since CHW basic training if a CHW)	-0.698	0.344	-2.144	0.748

Reported using margins dy/dx to give the discrete change from baseline for factor levels; All exposures given as provincial-level summary measures; * <0.05; Ψ <0.10

Table 9. Marginal change (dy/dx, 95% confidence interval) in the third dose of pentavalent coverage for each 10-percentage point change in covariate (unless otherwise specified) for associated covariates ($p<0.05$ and $p<0.10$) while controlling for the proportions of poorest and middle-income households in a province

Exposure	**Percentage point change (dy/dx)**	**p-value**	**95% CI, (LL)**	**95% CI, (UL)**
PENTA coverage (provincial) in 2007-08	2.388	<0.0001*	1.514	3.261
2009-10 versus 2008-09	2.555	0.441	-3.941	9.051
2011-12 versus 2008-09	3.359	0.399	-4.443	11.161
2012-13 versus 2008-09	2.309	0.530	-4.904	9.522
Proportion of households that are in the *poorest* wealth quintiles	0.311	0.759	-1.677	2.298
Proportion of households that are in the middle wealth quintiles	3.207	0.003*	1.060	5.353
Proportion of households (who had at least one sick member of the household in the past two weeks) that are less than 2 hours from the nearest health facility	1.740	0.052Ψ	-0.019	3.498
Proportion of ever-married women ages 12-49 years who have ever attended school	4.984	0.058Ψ	-0.163	10.131
Proportion of ever-married women ages 12-49 years who have had a live birth delivery and the child is still living who exclusively breastfed	2.854	<0.0001*	1.280	4.429
Proportion of women who had a healthy delivery outcome in the past 2 years who received their first and second doses of the tetanus toxoid vaccine during pregnancy	1.447	0.285	-1.206	4.099
Proportion of ever-married women ages 12-49 who are aware of community health workers (CHWs) and who agree/strongly agree that CHWs provide useful services	0.450	0.301	-0.404	1.304
Average vaccine-specific lab score	1.508	0.037*	0.088	2.928
Average vaccine-specific stock score	3.915	0.040*	0.174	7.657
Proportion of health workers who have received vaccine-specific training in the past six months (or since CHW basic training if a CHW)	-0.854	0.233	-2.255	0.548

Reported using margins dy/dx to give the discrete change from baseline for factor levels; All exposures given as provincial-level summary measures; * <0.05; Ψ <0.10

Table 10. Marginal change (dy/dx, 95% confidence interval) in the third dose of pentavalent coverage for each 10-percentage point change in covariate (unless otherwise specified) for associated covariates (p<0.05 and p<0.10) while controlling for the proportion of middle-income households in a province

Exposure	**Percentage point change (dy/dx)**	**p-value**	**95% CI, (LL)**	**95% CI, (UL)**
PENTA coverage (provincial) in 2007-08	2.385	<0.0001*	1.517	3.253
2009-10 versus 2008-09	2.527	0.446	-3.974	9.028
2011-12 versus 2008-09	3.317	0.404	-4.469	11.103
2012-13 versus 2008-09	2.272	0.535	-4.915	9.459
Proportion of households that are in the *middle* wealth quintiles	2.916	<0.0001*	1.716	4.116
Proportion of households (who had at least one sick member of the household in the past two weeks) that are less than 2 hours from the nearest health facility	1.607	0.055Ψ	-0.036	3.250
Proportion of ever-married women ages 12-49 years who have ever attended school	4.285	0.006*	1.227	7.342
Proportion of ever-married women ages 12-49 years who have had a live birth delivery and the child is still living who exclusively breastfed	2.978	<0.0001*	1.930	4.026
Proportion of women who had a healthy delivery outcome in the past 2 years who received their first and second doses of the tetanus toxoid vaccine during pregnancy	1.644	0.191	-0.822	4.109
Proportion of ever-married women ages 12-49 who are aware of community health workers (CHWs) and who agree/strongly agree that CHWs provide useful services	0.437	0.313	-0.411	1.285
Average vaccine-specific lab score	1.520	0.035*	0.107	2.932
Average vaccine-specific stock score	3.894	0.041*	0.161	7.627
Proportion of health workers who have received vaccine-specific training in the past six months (or since CHW basic training if a CHW)	-0.843	0.239	-2.248	0.562

Reported using margins dy/dx to give the discrete change from baseline for factor levels; All exposures given as provincial-level summary measures; * <0.05; Ψ <0.10

Table 11. Marginal change (dy/dx, 95% confidence interval) in the third dose of pentavalent coverage for each 10-percentage point change in covariate (unless otherwise specified) for associated covariates ($p<0.05$ and $p<0.10$) while controlling for the proportion of richest households in a province

Exposure	**percentage point change (dy/dx)**	**p-value**	**95% CI, (LL)**	**95% CI, (UL)**
PENTA coverage (provincial) in 2007-08	2.966	<0.0001*	2.073	3.858
2009-10 versus 2008-09	2.561	0.463	-4.283	9.405
2011-12 versus 2008-09	2.998	0.475	-5.233	11.230
2012-13 versus 2008-09	1.891	0.633	-5.867	9.649
Proportion of households that are in the *richest* wealth quintile	-0.627	0.540	-2.631	1.378
Proportion of households (who had at least one sick member of the household in the past two weeks) that are less than 2 hours from the nearest health facility	1.065	0.238	-0.703	2.833
Proportion of ever-married women ages 12-49 years who have ever attended school	2.689	0.346	-2.905	8.283
Proportion of ever-married women ages 12-49 years who have had a live birth delivery and the child is still living who exclusively breastfed	2.180	0.006*	0.620	3.741
Proportion of women who had a healthy delivery outcome in the past 2 years who received their first and second doses of the tetanus toxoid vaccine during pregnancy	1.807	0.202	-0.966	4.580
Proportion of ever-married women ages 12-49 who are aware of community health workers (CHWs) and who agree/strongly agree that CHWs provide useful services	0.797	0.121	-0.210	1.804
Average vaccine-specific lab score	1.619	0.047*	0.018	3.219
Average vaccine-specific stock score	5.187	0.008*	1.365	9.008
Proportion of health workers who have received vaccine-specific training in the past six months (or since CHW basic training if a CHW)	-0.681	0.338	-2.073	0.711

Reported using margins dy/dx to give the discrete change from baseline for factor levels;

All exposures given as provincial-level summary measures; * <0.05; Ψ <0.10

Table 12. Marginal change (dy/dx, 95% confidence interval) in the third dose of pentavalent coverage for each 10-percentage point change in covariate (unless otherwise specified) for associated covariates (p<0.05 and p<0.10) by wealth status model

Wealth status as a covariate:	Poorest model	Poorest and middle-income model	Middle-income model	Richest model
Past coverage	2.619 (1.748, 3.490)	2.388 (1.514, 3.261)	2.385 (1.517, 3.253)	2.966 (2.073, 3.858)
Time	-	-	-	-
Wealth status	-1.755 (-2.881, -0.628)	3.207ΨΨ (1.060, 5.353)	2.916 (1.716, 4.116)	-
Traveling distance to nearest facility	-	1.740* (-0.019, 3.498)	1.607* (-0.036, 3.250)	-
Educational status, women	-	4.984* (-0.163, 10.131)	4.285 (1.227, 7.342)	-
Exclusive breastfeeding practice	3.436 (2.089, 4.783)	2.854 (1.280, 4.429)	2.978 (1.930, 4.026)	2.180 (0.620, 3.741)
Second dose tetanus toxoid during pregnancy	3.004 (0.366, 5.642)	-	-	-
Awareness of CHWs and their value		-	-	-
Vaccine-lab	1.645 (0.176, 3.115)	1.508 (0.088, 2.928)	1.520 (0.107, 2.932)	1.619 (0.018, 3.219)
Vaccine stock	4.341 (0.571, 8.112)	3.915 (0.174, 7.657)	3.894 (0.161, 7.627)	5.187 (1.365, 9.008)
Vaccine re-trained health workers	-	-	-	-

* p<0.10; Ψ only poorest; ΨΨ middle-income

Intended to be blank.

Chapter 4. The subsystems of an immunization system: using causal loop diagrams to identify pathways through which readiness to deliver immunization services may affect health service outcome performance in the Afghan health system (Paper 2)

Abstract

Background. This study aimed to map the structure of the Afghanistan routine immunization system using causal loop diagrams to identify causal pathways through which immunization system readiness may affect immunization- and non-immunization performance.

Methods. A rapid literature review was conducted to identify routine immunization system components and their relationships. Its findings as well as findings from an ecological study examining the Afghanistan immunization system (Study 1) were used for an iterative causal loop diagram (CLD) development process. Content and methods experts with varying professional backgrounds reviewed the CLDs and provide feedback. CLDs were reduced and combined with the intent to guide System Dynamics modeling for model confirmatory exercises.

Results. Four CLDs were created according to four subsystems of the Afghanistan routine immunization system. A theme of system actors, both demand- and supply-side, emerged from the CLDs where actors often serve as links between supply and demand. Laboratory capacity does not link directly with service delivery but affects governance, political and financial commitment, and stocks of health worker knowledge and skills at health facilities. *Demand loops* supported the structure of three of four subsystems. Components proximal to *vaccination service provision capacity* are: *vaccines at facilities* through good *vaccine management* and amply *functioning cold chains*, *vaccine stocks moved to communities* for outreach, *health worker knowledge and skills, number of health workers* and their *workloads* and ability to *adapt services* to improve vaccination service availability. Non-immunization outcomes were most

proximally affected by *technical* and *perceived quality of care* as well as population characteristics.

Conclusion. CLDs are useful for examining complex, adaptive systems. The role of laboratories and surveillance in routine immunization systems, the intersection of supply-demand, and demand-side actor behavior and related factors are important areas to explore for improving current understanding about immunization system behavior in Afghanistan, especially at lower-levels of analysis.

4.1 Introduction

More than forty years ago in 1974, the WHO launched the EPI (Lim et al., 2008; Shen et al., 2014; WHO, 2011b). Since then, most low- and middle-income countries have developed national immunization programs based on the EPI scheme. Programs have become increasingly complex with rising costs, added vaccines in the routine schedule, hard-to-reach populations, increased demands on cold chain infrastructure and logistics, and exogenous threats like civil unrest and conflict (Shen et al., 2014) not to mention concerns about trust building, community participation, and service delivery adaptation (Butler & MacDonald, 2015; Ozawa et al., 2016; Ozawa & Stack, 2013). Despite representing one area of service delivery in a health system, the immunization system is an example of *complexity*, which indicates that it represents a series of relationships and adaptive interactions of its components in the emergence of a whole (system) (Greenwood-Lee, Hawe, Nettel-Aguirre, Shiell, & Marshall, 2016). In order to understand how immunization system *complexity* may impact immunization coverage outcomes and spillover to affect other non-immunization coverage outcomes, we mapped pathways through which immunization service-readiness may affect outcome performance in immunization and non-immunization service domains in the Afghan health system, starting by defining the main subsystems of the immunization system that contribute to immunization outcomes.

4.2 Background

Routine immunization is a core subsystem and area of care in country health systems. It often is a part of basic packages of health services. Routine immunization has a horizontal nature coupled with vertical program characteristics that include its campaign activities, intervention-specificity, disease elimination targets, and specific target populations and diseases. Routine immunization has been referred to as an *essential platform*, *critical subsystem*, and a component that is *both dependent upon and strengthening* the host health system (Clements et al., 2011; Shen et al., 2014; Sodha & Dietz, 2015; Steinglass, 2013; Susan A Wang et al., 2012).

A *system* is a set of "things" interconnected in such a way that they produce their own pattern of behavior over time, and the key to understanding their behavior is to examine their structure (Meadows DH, 2008). Therefore, a *health system* is a set of components that are interconnected and designed with the intention to support positive health outcomes. An *immunization system* could similarly be defined but with the intention to support positive, immunization-specific outcomes. With one situated within the other, the series of relationships and adaptive interactions driven by feedback (*complexity*) involved in the immunization system are not isolated but rather interact with the *complexity* of its host health system.

Boundaries between one area of health service delivery and another are likely blurred, e.g. human resources for vaccination are likely shared resources for other basic primary health care services. Even within the immunization system, different areas of *system readiness* (capacity for effective service delivery (Ozawa et al., 2016)) will overlap, e.g. human resources capacity may span those who contribute to logistics and management capacity as well as for health workers who are health service providers. Depending on the *system* or *subsystem*, boundaries can be shifted. For example, researchers in Uganda examined the immunization system and how to improve performance (measured as immunization coverage) and subdivided the immunization system into four subsystems: immunization management, community, vaccines management, and healthcare service (A. S. Rwashana et al., 2009).

The pathways through which immunization systems interact with host health system are just starting to be examined using methods that enable users to account for *complexity*. Evidence suggests that strong routine immunization platforms can generate policy and financing innovations for the health system (Lahariya, 2015; Shen et al., 2014; Tapia-Conyer, Betancourt-Cravioto, Saucedo-Martínez, Motta-Murguía, & Gallardo-Rincón, 2013). Immunization-specific logistics and cold chain subsystems can strengthen the movement of resources around the health system (Lahariya, 2015; Shen et al., 2014). Trained human resources particularly skilled in management, logistics, surveillance, and regulation may bolster the healthcare workforce in health systems, and the sheer number of required encounters with the health system throughout the immunization schedule represents opportunities to interact with parents, educate them on vaccines, and build rapport (Cappelen, Mæstad, & Tungodden, 2010; Shen et al., 2014; Sodha & Dietz, 2015). Community engagement strategies for immunization could improve community ownership of health programs, build members' skills in planning, implementing, monitoring, and advocating, and foster environments for equity- and trust-building that permeate into generalized trust in other public services (Cappelen et al., 2010; Gilson, Palmer, & Schneider, 2005; Ozawa et al., 2016; Ozawa & Stack, 2013; Shen et al., 2014; Varghese, Kutty, Paina, & Adam, 2014).

Many of these pathways transcend immunization service readiness and apply to other areas of service delivery, e.g. skills in management, logistics, and surveillance that translate to applied skills for health service delivery in general. Pathways also transcend the supply-demand divide and apply to communities and individuals, e.g. fostered environments of trust, equity, and community ownership that may contribute to individual, household, and community health seeking behavior habits or norms. Because child health is often linked to maternal health, it is of interest to focus on their connecting pathways that link system readiness in immunization to performance outcomes (coverage) in both.

When pathways lead to other areas of service delivery, maternal health service systems could be acting synchronously with the immunization system. Whether the linked behavior produces positive or negative tradeoffs is less known. Health care seeking for mothers and children is similar (Cardol et al., 2005; Hu, Li, Chen, Chen, & Qi, 2013; McGlynn, Wilk, Luginaah, Ryan, & Thind, 2015; Wado, Afework, & Hindin, 2014). A child's health is typically the immediate responsibility of mothers. Studies have shown an association between child immunization and maternal health services such as ANC, facility-based deliveries, and SBA (Babalola & Fatusi, 2009; McGlynn et al., 2015). Incomplete vaccination has been linked with non-use of maternal-child health services, living in conflict-affected areas, cancelled vaccination sessions, and missed opportunities for vaccination (Sodha & Dietz, 2015). Moreover, there may be a link between increased utilization of maternal health services and appropriate care for childhood illnesses (McGlynn et al., 2015).

SD is a subfield within systems science in which feedback-driven behavior of systems has been studied for decades by translating real-life systems into computer simulation models that allow researchers to examine how system structure and changes to policies can alter system behavior (Forrester, 2009). Qualitative and quantitative methods (e.g. CLDs, stock and flow diagrams, SD models) offer the opportunity to account for *complexity* attributes such as feedback loops, systemic delays, and the unintended consequences and intended consequences due to exogenous shocks or differing policy scenarios (T. Adam & de Savigny, 2012; R. Atun, 2012; Forrester, 1971; J. Homer, Hirsch, Minniti, & Pierson, 2004; A. S. Rwashana et al., 2009; A. Rwashana & Williams, 2008; Varghese et al., 2014; WHO; Alliance for Health Policy and Systems Research, 2009). Subsystem-system relationships in health and particularly immunization (i.e. vertical-horizontal relationships) have been explored without accounting for system structure and feedback. Research to-date is insufficient for examining the dynamics within the immunization system and its relationship to the broader health system. Researchers in Uganda used CLDs and SD modeling for exploring pathways within the immunization system that lead to improved routine immunization coverage (A. S. Rwashana et al., 2009; A. Rwashana & Williams, 2008), and Ozawa et al. (2016) recently published CLDs that explore pathways of building trust in vaccines and health system resiliency. We could find no examples that examined the pathways connecting the routine immunization system structure with immunization and non-immunization service coverage outcomes using methodologies that account for feedback-driven behavior.

We designed a qualitative case study that combined a rapid, non-exhaustive review of the literature, secondary data analysis, and CLD-building exercise to explore the relationship between the immunization system and health system by identifying pathways through immunization system readiness may impact immunization- and non-immunization performance. This qualitative case study has two main objectives:

3) To map the dynamics of the Afghanistan immunization system by developing CLDs that include the main system components and connections
4) To identify pathways through which immunization system components may affect outcomes in immunization performance (coverage of third dose of pentavalent vaccine) and non-immunization service performance

Given the evidence, maternal health service outcomes (i.e. SBA, ANC, tetanus toxoid vaccination) and childhood illness treatment services (treatment of acute respiratory infections) were considered for their linkages to the immunization system. CLDs from this study will serve as a basis for future SD modeling and system confirmatory exercises.

4.3 Methods

4.3.1 Literature review

A non-exhaustive, rapid review of literature on the readiness to deliver immunization services in low- and middle-income countries (especially in fragile states) and immunization system structure was conducted in PubMed, Scopus, and Embase using combinations of key terms such as 'immunization', 'vaccination', 'immunization programs, 'delivery of health care, 'health services, 'systems analysis', and 'maternal health services'. We included articles and reports from previous work on immunization services and programs. Findings on immunization program components, structure, and linkages to the health system and its performance were most useful. Immunization system components were further categorized and supported by context-, content-, and methodology-knowledge (Afghanistan, immunization programs in low- and middle-income countries, health service delivery, systems thinking and modeling).

4.3.2 CLD development

Investigators created initial lists of subsystem-system components and definitions of relationships. These lists were refined based on the triangulation of the data from the different sources including empirical findings from a secondary data analysis (Chapter 3). Themes were identified emerging from common domains of service delivery (Edward et al., 2011; Peters et al., 2007; WHO, 2007) in health systems and within immunization systems (e.g. supply chain (cold chain) capacity, stock and inventory of supplies at different levels of the system/subsystem, human resources for delivering services (vaccination), surveillance (lab) capacity for case confirmation, demand capacity). We used these service delivery readiness domains to help define immunization subsystem boundaries. The main immunization outcome of interest was vaccination coverage of the third dose of the pentavalent vaccine (Penta3). The main non-immunization outcomes of interest were coverage estimates of the following health services: ANC, SBA, children with acute respiratory-infection (ARI)-like symptoms who were taken to a health facility for treatment, and tetanus toxoid vaccination

Mental models were created in the form of CLDs using Vensim PLE (Ventana Systems, 2015). CLDs were refined through five revisions. Complex Adaptive Systems (CAS) theory supported the development of the CLDs, a paradigm which is useful for exploring factors that are influential in the immunization subsystem of Afghanistan and the characteristics that support CAS behavior, like self-organization, adaptation, and learning from past experiences (Taghreed Adam et al., 2012; Paina & Peters, 2012; Varghese et al., 2014). Using knowledge of CAS behavior (i.e. path dependence, feedback loops, scale-free networks, emergent behavior, and phase transition (Paina &

Peters, 2012)), the student, who has basic training in CLD building, field experience in Afghanistan, and consulting experience focused on immunization systems and demand at the WHO, created four subsystem CLDs that together depict the immunization system of Afghanistan (those focused on point-of-service-delivery health workers, functional cold chains and vaccine supply, basic laboratory and surveillance capacity, and consumer health seeking behaviors and household/individual characteristics).

The recommended notation from SD literature was used to label polarity, directionality of causal relationships, and feedback (Kim, 1992; Lane, 2008). To further help with CLD interpretation, an "O" was used to indicate a causal relationship of uncertain directionality. Dotted lines of arrows indicate a causal relationship of uncertain existence. Color codes of green and red were used. *Green* variables indicate a component that is a part of more than one subsystem. *Red* variables indicate a component that is a part of a system of care other than that of immunization (see Table 13 for full list of *green* and *red* variables). Boxed variables indicate quantities that change with time (i.e. what are known as "stocks" in preparation for the next stage of the full research project, which includes SD modeling). Feedback loops were labelled as 'R' or 'B' for their reinforcing or balancing nature, and their nature was determined by multiplying the relationships involved in the loop (A. S. Rwashana et al., 2009). Each loop was numbered for cataloging purposes. Loops were further categorized as stand-alone loops or loop variations, which exist where the majority of components in two loops are the same with the exception of a small but unique change in the proposed causal pathway. If loops shared the majority of common components with another and the only difference represented a minor alternative pathway, loops were then deemed as *variations* and labeled with lower case letters (i.e. R1b represents a variation of the main loop R1a).

Causal pathways were checked and re-checked to ensure that each remained intact and/or improved from iteration to iteration. The second iteration more clearly shaped subsystem boundaries, preparing for an expert review process.

4.3.3 Model Validation and Finalization

A validation process was carried out, soliciting feedback from methods, context, and content experts. This process was approved by the Institutional Review Board at the Johns Hopkins Bloomberg School of Public Health and deemed as non-human subjects research. An initial group of thirteen experts were identified for their expertise in immunization and immunization programs, health service delivery systems and tradeoffs, immunization and health policy, and Afghanistan or developing country contexts of any of the previously mentioned content areas. Experts had backgrounds in immunization policy development, immunization program monitoring and evaluation, country-level immunization program management (in developing countries), technical support to national immunization programs in the areas of surveillance, community engagement, and program management, community engagement and communication for immunization in developing countries, medical practice and research in Afghanistan, and local knowledge of Afghanistan. They represent private and public organizations, government and multi-lateral organizations, academic institutions, and local Afghan organizations and government. These experts were asked to review and provide feedback on the four subsystem CLDs. Participants were contacted via email or by phone and asked to answer a series of questions either by email correspondence or by phone. In addition to general comments, the following questions were asked:

- Do all the diagram variables belong in the CLD?
- Do all the connections among these variables belong in the CLD?
- Are there missing factors of the system represented in this CLD that should be included?
- Are there any extra factors in the system represented in this CLD that should be excluded?
- Should any of the directions of the mechanistic relationships (arrows) be reversed?

Comments were consolidated and incorporated into the CLDs as the third, fourth, and fifth iterations of diagrams. We adjusted CLDs as expert feedback was received. Updated models were used for subsequent feedback surveys. In total, seven experts participated in the CLD review after which the investigators considered the validation process “complete” based on saturation and quality of feedback. Review and discussion of the expert feedback, current evidence, future data needs, and the feasibility of SD model development supported model improvements. In the third through fifth CLD iterations, investigators made better use of the *green* variables to link the subsystems together gaining a better picture of the full immunization system.

This paper presents four subsystem-focused CLDs that were shaped through the validation process. Collectively, they represent the full immunization system in Afghanistan. Following the validation process, the CLDs were refined in order to better understand the bolstering structure of the system and what components and relationships may drive system behavior. This process was used to prepare for creating system dynamics (SD) models (Chapter 5) for a confirmatory exercise. The three following steps were followed 1) reducing each full subsystem by identifying main feedback loops that can be further supported with available empirical data; 2) simplifying the feedback loops where pathways can continue through components that do not have available data; and 3) joining the four reduced and simplified CLDs.

4.4 Results

We created four final CLDs. Each CLD represents a different subsystem. Together the CLDs depict the immunization system of Afghanistan. The four subsystems are: 1) functional cold chain and adequate vaccine supply at health facilities; 2) basic laboratory and surveillance capacity at health facilities; 3) health workers and their capacity; and, 4) household and individual characteristics. Each subsystem had numerous feedback loops and variations (Table 14).

4.4.1 Subsystem 1 – cold chain and vaccine stocks

SS1 focus and boundaries

The first subsystem (SS1) explores the dynamics in cold chain functionality and vaccine stock flows through the immunization system. Boundaries were defined by concentrating SS1 behavior on the movement of vaccines through the country and how it impacts service capacity [availability of services] at health facilities and service utilization. We depicted vaccines starting at the central level (*viable vaccine stock at central storage*) and moving through the cold chain to eventually end up as the viable vaccine stock at facilities. Vaccines can also continue to move to the community for vaccination outreach efforts. To simplify interpretation of the first subsystem, we show SS1 in parts, examining the main pathways and their corresponding components.

SS1 components and connections

In balancing loop (B3) vaccines are delivered to facilities whenever vaccine stock runs out or low, assuming that not all facilities are in need of more vaccines (Figure 5). This represents a basic traditional supply and demand loop as it follows the path of vaccine stock through the subsystem. The amount of *stock movement…via the cold chain* (top left) is a reflection of the monthly vaccine stock movement from regional to provincial storage by road. Thereafter, vaccine stock is transported by road to provincial level storage and subsequently health facilities for vaccination. This stock movement is the systematic, routine part of vaccine movement through the cold chain to finally reach health facilities for vaccination delivery. Provincial data about these storage levels and transports are not available in our datasets, so the details of this transport system are summarized in the *stock movement: viable vaccines transported via cold chain from central, to regional, to facilities* component.

If, for example, the amount of *viable vaccines moving through the different levels of the cold chain* decreases or does not keep up with demand, the amount of *viable stock at facilities* is likely to also decrease. Following this decrease in stock at facilities, the gap between the viable vaccine stock at facilities and demand at facilities (*children present at facilities for vaccination*) may increase. If this gap increases, the *identification of that gap* also should increase and cause more *ordering of vaccines* to correct the viable vaccine stock at facilities. As more *ordering* occurs and/or the amount ordered increases (identified from the *gap*), the *amount of stock moving through the cold chain* may increase to improve the amount of *viable vaccine stock at facilities*.

The + and – indications of causality allow interpretation of the opposite scenario using loop B3 where *the amount of stock moving through the cold chain* may increase, causing *the amount of viable vaccine stock at facilities* to also increase. After moving through the scenario of decreasing the *gap* between demand and *vaccine stock availability* and decreasing the occurrence or need for *ordering*, the resulting effect of the reinforcing loop is a reduced *amount of vaccine stock* (or reduced amount of additional vaccines) *moving through the cold chain*.

The balancing loop of vaccine stock movement through ordering and replenishment changes to a reinforcing loop when considering the *gap between vaccine stock at central storage,* the *ordering* efforts to improve response to demand at facilities, and the impact on *stock movement:…via cold chain*.

Reinforcing loop R1a (Figure 6) introduces a varying pathway. Instead of directly affecting *stock movement,* a change in *ordering* directly affects the *gap between vaccine stocks at central storage* and estimated correcting *demand (*through *ordering)*. If stock movement through the cold chain decreases and the amount of vaccine stock at facilities decreases to lead to an increase in lower-level gaps, then more ordering will take place to meet the need. If ordering increases, then higher-level gaps may also increase assuming flows of vaccine stock into these higher levels remains constant. If this higher-level gap increases, the amount of stock moving through the cold chain will likely decrease, further perpetuating a decrease in the amount of viable vaccine stock at facilities. This is an example of a reinforcing feedback loop of subsystem behavior where an initial decrease yields a future decrease, or an initial increase yields a future increase. The virtuous or vicious cycle is expected to continue.

The R1 loop does not happen in isolation. In Figure 7 *good vaccine management* affects the *viable vaccine stock at facilities* as well as identification of the *facility supply-demand gap*. If we have better *vaccine management* (including dose wastage management), then we would expect to have more *viable vaccines at a facility* by limiting *wastage* or preventing stock *expiration*. We also expect that better *vaccine management* would also improve the identification of the *supply-demand gap* of vaccine stocks at facilities. These cause-and-effects are also a part of the R1b loop variation.

A variation to the R1a loop, R1b, goes through the effects of *vaccine stockout events at a level higher than facilities* (possibly central storage level) (Figure 7). Beginning with a decrease in the amount of *viable stock at central storage*, the *gap* between what is available and what is needed at lower levels (as indicated by reordering) may increase. If this *gap* between supply and demand increases, the occurrence of *vaccine stockouts* may also increase causing the amount of *vaccines moved through the cold chain* to decrease. Three delays are included in the R1 loop and R1b variation: a time delay in the effect that the amount of viable vaccine stock at central stock has on the vaccine stock moved through the cold chain and thereafter down to the amount of vaccine stock at facilities. There may also be a time delay in the causal pathway linking identification of the supply and demand *gap* experienced at facilities and acting on knowledge of the gap to *order* more vaccines.

One additional loop (B1) affects R1 loop variations and loop B3 (also Figure 7). Logisticians play a key role in *vaccine management*, and if their *knowledge, skills, and experience* increase, then a gap with *the desired fluency for adapting the cold chain and storag*e should decrease. If this decreases, then the amount of *re-training* that occurs may also decrease, and if this decreases too much, there may be a decrease in the stock of *knowledge, skills, and experiences*. If this stock decreases, then *good vaccine management* may decrease as well. The time delay that may occur between the *gap* in stock availability and demand and the *identification* of that gap is likely affected by *vaccine management*, i.e. good *vaccine management* may reduce that delay.

The last part of SS1 contains two feedback loops. Balancing loop B2 and reinforcing loop R3 both include elements of demand for vaccination that directly or distally affect the number of vaccinated children. Beginning at the *green* variable on the left in loop B2, if the number of *children present at the facility for vaccination* increases (demand as an action of seeking services) and the amount of *viable vaccine stock at facilities* and all other variables are held constant, the *gap* between vaccines at facilities and this demand will also increase. If this *gap* increases with all other variables held constant, it is possible that *facility-level stockouts* increasingly occur or are at risk for occurring more often. If the event of *vaccine stockouts* increasingly occurs, then the *parents' knowledge and experience of stockouts* when seeking services will increase. If these *experiences* occur more frequently, then the immediate, active demand (having *children at facilities for vaccination*) will decrease.

The B2 and R3 loops work closely together. If *knowledge and experience of vaccine stockouts* increases among parents, then the number of *messages* created and passed along by parents about the vaccine stockouts will increase. If the quantity of *negative messaging* increases, then the public's *association of stockouts with other vaccines* (rather than associated with the single vaccine that is out-of-stock) will also increase whereas the frequency of subsequent *decision(s) to go to facilities* for vaccination services (passive demand) will decrease. A decrease in the frequency of *decision(s) to go to the facility* for vaccination will cause a decrease in the number of *children at the facility for vaccination*. Together, active demand (number of *children at the facility for vaccination*) and *vaccination service provision capacity (availability of services)* at the facility directly affect the number of *vaccinated children*.

SS1 vaccination service readiness and vaccination outcome pathways

The full SS1 (Figure 8) contains seven green variables, connecting SS1 to other subsystems. They are: 1) *Good vaccine management* (including wastage management); 2) *demand: children at facility for vaccination*; 3) *demand: decision to go to facility* (in this case, for vaccination); 4) *vaccinated children*; 5) *vaccination service provision capacity [availability] at facilities*; 6) *vaccination service provision capacity [availability] for outreach*; and, 7) *outreach activities*. Causal pathways arrive at a primary outcome of interest, i.e. *vaccinated children*. In order to link *vaccine stocks at facilities* with *vaccination events*, *vaccine stocks* were treated as components that contribute to *vaccination service provision capacity* (i.e. overall availability of vaccination services at facilities). Additional components were added to describe the occurrence of *vaccine stocks* (supply) not meeting the need based on the number of *children at the facility for vaccination* (demand) and the factors contributing to these events (e.g. *good vaccine management*, *stock movement* and responsiveness to varying need (*ordering* and *higher-level vaccine stockouts*), *parents informed about stockouts, etc.*). Components relating to vaccination *outreach activities* show that *vaccine stock* availability and *cold chain functionality* are not limited to the levels leading down to health facilities but that storage capacity and campaign-related readiness also contribute to the number of *vaccinated children*, though this differs from the routine immunization-focus of this study.

4.4.2 Subsystem 2 – basic, vaccine-related laboratory capacity at health facilities

In the next subsystems, pathways arrive at other outcomes of interest (like *deliveries with skilled birth attendants present*). While the number of *vaccinated children* was depicted as an effect in SS1, outcomes in subsystems two through four (SS2-4) may distally affect themselves (feedback) and other outcomes. Like SS1, SS3 and SS4 integrate elements of population-side characteristics that also impact health service coverage outcomes.

SS2 focus and boundaries

The second subsystem (SS2) focuses on exploring the dynamics in basic vaccine-related laboratory capacity and its relationship to vaccination coverage in the Afghan health system (Figure 9). Boundaries were defined by concentrating SS2 behavior on the relationship among *facility basic laboratory capacity*, *infectious disease surveillance*, and *awareness for surveillance among local authorities* and *health workers*. This CLD has three reinforcing loops with five loop variations.

SS2 components and connections

In R1a and R1b loop variations (Figure 10), if *facility basic laboratory capacity* improves (center), there may be an increase or improvement in *case confirmation*. Through improved *laboratory confirmation of cases* and subsequent improvement in *infectious disease surveillance* in the country over time, *awareness for surveillance among local authorities* may improve, which would positively reinforce future *basic capacity at facilities*. An alternative pathway begins at *awareness for surveillance among* *authorities* and forms the loop variation R1b. Improved *awareness* would contribute to improved *advocacy through global partners*, improved *funding for surveillance and laboratory activities*, and more *resources for functioning basic laboratories*, which would positively impact *facility-based laboratory capacity*. Opposite effects (negative, declination, worsening) could alternatively be observed and would be reinforced through these same loop variations.

In R1e (Figure 11) through the improved *resources for functioning basic laboratory* pathway, the improved *lab-confirmed cases* remains the same as in the R1a-b variations. The R1e variation is the same as the R1b pathway except that resources for laboratories lead to *national and/or regional laboratory capacity improvements* instead of facility-level. These *improvements* would likely improve the occurrence of *lab-confirmed cases*, completing the reinforcing feedback loop. The R1c variation depicts a potential causal pathway from increased *funding for surveillance and laboratory activities* to an increase in *trained laboratory staff*, which may also contribute to improved *laboratory capacity at facilities*. Variation R1d is an alternative pathway that leads causation from *lab-confirmed cases* to *health worker knowledge and skill base at facilities* where an increase in *trained laboratory staff* may contribute to improvements in the *health worker knowledge and skill base* and improve *laboratory-confirmed cases*. Loop R3 depicts the reinforcing nature of *awareness* and *advocacy*, which contributes to *funding support*.

In Figure 12 loop variations R2a-b depict how improved *infectious disease surveillance* can lead to improved *awareness among health workers*. Improved *awareness among health workers* may contribute to an increase in *knowledge and skills* among health workers. This increase may lead to an increase in *lab-confirmed cases* (met by *trained laboratory technicians* to affect *lab-confirmed cases* in Figure 11), which may lead to improved *infectious disease surveillance*. The R2b loop variation relies on a relationship from subsystem 3. Through a series of cause-effect relationships, an improvement in *health worker knowledge and skills at facilities* would contribute to an improvement in *technical quality of service provision*. An increase in *technical quality* may improve case identification based on non-laboratory diagnostics, which would improve *lab-confirmed cases*.

SS2 vaccination service readiness and vaccination outcome pathways

No direct link to *vaccination events* (i.e. coverage) is depicted in the full SS2 model (Figure 9). Two green variables (*technical quality of service provision* and *health worker knowledge and skill base at facilities)* are included in SS2 that also appear in other subsystems (SS3 and SS4). Therefore, components of SS2 have a distal relationship to *vaccination coverage*.

4.4.3 Subsystem 3 – health workers and their knowledge, skills, and experience

SS3 focus and boundaries

The third subsystem (SS3) focuses on the dynamics involved in the relationship across health workers, their knowledge, skills, and experience at facilities, vaccination coverage, and non-immunization service coverage. SS3 has four balancing loops and one reinforcing loop, and each loop has one or more variations except for loop B4. Boundaries were defined by focusing SS3 behavior on the role of health workers in the immunization system. We chose to focus on how health worker motivation (and their accompanying attitudes) affects their performance (both perceived and technically).

Moreover, it is health workers who may be the main connection that links supply (program/system readiness to deliver health services) and demand (readiness to use and actual use of those health services) in the immunization system. Health workers are in a unique position where their main role is to engage with health system users, including in situations for providing information and building rapport as well as at the point of service delivery. For this reason, components of demand, trust, and non-immunization service outcomes are included in the scope of SS3. We present SS3 in sections to simplify the interpretation of its full construction.

SS3 components and connections

Loops B1 and B2 (Figure 13) focus on quality of care, demand for vaccination, and health worker workloads. These loops have *red* variables that attempt to link the immunization subsystem to performance in other health service domains (potentially other health subsystems). In B1a more *decisions (among parents) to have children vaccinated* lead to more *vaccination-seekers at facilities*. With more *vaccination-seekers at facilities*, the *workload of health workers* may increase and may change *health worker motivation*. The relationship is labeled as unknown ("o") because of other unknown factors that may contribute to health worker motivation (remuneration, scheduling, autonomy, etc.). An increase of *health worker motivation* may change how the health worker acts and his/her underlying attitude, which may improve the *perceived quality of care*. If *perceived quality* increases, the amount of *community trust* in the health system may gradually improve, which may support future *vaccination decisions*.

Improved *community trust* may also contribute to increased receipt of other health services such as *ANC* among pregnant women (loop B1b). Improvements in coverage of

ANC may further support future *decisions to have children vaccinated* because of information on childhood vaccination that is given and reinforced during ANC visits. An increase in *pregnant women receiving ANC* may lead to future *SBA* and a subsequent increase in future *vaccination-seekers at health facilities*, for examples, for vaccinations given at a birth (loop B1c). An increase in SBA may also contribute to an increase in future vaccination decisions.

The B2 loop series (Figure 13, bottom) works through changes in pathways focused on *health worker workload* and *health worker motivation*. An increase in *health worker motivation* may lead to improvements in *technical quality of care* followed by improved *perceived quality of care* (B2a) and the number of *vaccinated children* (because of the presence of health workers who, for example, check immunization records for any missing vaccinations) (B2b). In variation B2c improved *technical quality of care* may increase *pregnant women receiving a tetanus toxoid (TT) vaccination* as result of a health worker recognizing that a woman is eligible for the TT vaccination when at the health facility for a reason other than to specifically receive the TT vaccination.

In the next part of SS3, the R1a loop examines the effects of *health worker workload* on the *number of health workers at facilities* (Figure 14). If the number of *health workers at a facility* increases, then the *health worker workload* may decrease. If the *workload* decreases, then the *stress level* and *health worker turnover* may decrease. If *health worker turnover rates* decrease, then the *number of health workers at a facility* may improve or be maintained. The R1b variation includes *vaccine service capacity (availability of services)*, showing that as the *workload* increases, the *service capacity* may suffer. If *service capacity* weakens, then the *stress level* may increase, contributing to higher *turnover* and fewer *health workers at facilities*.

Loop B3a, variation of R1a, changes components and the behavior of feedback from reinforcing to balancing. As the *number of health workers* at a facility increases, the immunization *outreach activities* may improve or become more frequent. If this happens, then the *identification of pregnant women eligible for health services* may improve, which could improve future *SBA coverage* and contribute to the *number of vaccination-eligible children at facilities*. An increase of *vaccination-seekers* may contribute to the *workload*, which could cause an increase in *stress levels* and potentially more *health worker turnover*. More *turnover* may decrease the number of *health workers at facilities* and reduce *immunization outreach activities*. In the B3b variation the *identification of pregnant women* via *immunization outreach activities* may contribute to improved use of *ANC* and *SBA services*.

The last SS3 loop depicts the flow of health worker knowledge and training (Figure 15). An increase in the *desired level of knowledge and skills* (which may be affected by new technologies, changes to the national immunization program, etc.) contribute to an increase in the *knowledge and skill gap* between the desired and current knowledge and skills. If this *gap* increases, *vaccine-specific refresher training* may increase. This relationship is shown by a dotted-arrow because it is unclear whether such responsiveness exists in the Afghan system or even in other developing country contexts. If *training* increases, the stock of *health worker knowledge and skills* will increase. If the *knowledge and skills* stock increases, then the *knowledge and skill gap* will likely diminish.

SS3 vaccination service readiness and vaccination outcome pathways

When all SS3 parts are combined into a full subsystem CLD, the loops that involve *technical* and *perceived quality of service provision* as well as *trust* are those that support the SS3 framework (Figure 16). Facets of *health worker knowledge and skills base*, *number of health workers*, and *workload* together affect *vaccine service capacity* [*availability of services*], which are additions to the factors of *vaccine management* and *vaccine stock (supply) at facilities* that also affect *vaccine service capacity* [*availability of services*] in SS1 (Figure 8). It is through pathways that include *technical quality of care, trust* in services, and *capacity for outreach activities* that relatable areas of health services (e.g. from the maternal health domain) are involved in causal feedback loops of the immunization system of care. *Technical quality of care*, found in the B1 and B2 loop series, affects whether a woman may be identified for her tetanus toxoid vaccine during pregnancy; it also affects perceived quality of trust and the stock of *community trust in the health system* that grows over time and may affect future health care seeking decisions and behaviors, regardless of the type of health service or product sought. Because distance and transport are two common factors affecting women's health care access behaviors in Afghanistan (Tappis et al., 2016), *capacity for outreach activities* may likely be a separate component of *vaccine service capacity* [*availability of services*] that is particularly effective for identifying pregnant women for necessary health services but also for fostering future health care seeking behaviors like those for vaccination.

4.4.4 Subsystem 4 – household and women's characteristics

SS4 focus and boundaries

The last subsystem (SS4) explores the relationship across the characteristics of mothers and households, the Afghan context, vaccination coverage, and non-immunization service coverage. SS4 boundaries were developed according to two components: mother's educational status and household wealth status, which were found to be significant predictors of immunization coverage in Chapter 3. In SS4, education and wealth are linked to the supply-demand, access, and utilization relationships of SS3. SS4 has four reinforcing loops with variations, one balancing loop, and new *red* variables.

SS4 components and connections

The R1 loop displays the dynamic between *mother's education* and *household wealth status* (Figure 17, center). Each reinforces the other. Each affects a different influencer of demand. *Mother's educational status* has more of an affect on her *health decision-making*, which affects her decisions to seek health services. *Household wealth status* has more of an impact on a *mother's availability* to go to a health facility for care. Her *availability to go to a facility* is part of loop B1, which shows that as her *availability* increases, it is unclear whether the *health services in Afghanistan adapt* (or whether they are able to) to subsequently improve *vaccine service capacity* (or the overall availability of services). If the *adaptation* improves and the *capacity* improves, then a *mother's availability* improves by having changed the health service architecture. A *mother's availability* to go to a health facility would improve having *children at the facility for vaccination* (Figure 18).

Loop R3 is the second part of SS4 (Figure 18) that includes *demand*, *technical and perceived quality*, *trust*, and *vaccinated children*, which also appear in SS3 (Figure 15). The same causal pathways that link *demand* and *vaccinated children* together are exhibited: 1) through the *health worker workload* pathway, technical quality, perceived quality, trust, and demand; 2) through the *health worker workload* pathway, *technical quality*, *vaccniated children*, *community trust*, and *demand*; and, 3) through *vaccinated children*, *trust*, and *demand*.

In the final part of SS4, other influencers on the demand-vaccination status relationship are shown (Figure 19). Reinforcing loop R2 shows the reinforcing relationship between *ANC visits* and *decisions to go to the facility for services* (such as vaccination). Two variations (R4a and b) are shown that introduce other reasons that children may be present at facilities. We hypothesized that if women *receive ANC*, then their *awareness of child illnesses and symptoms* may also improve. This *awareness* along with the actual *severity of symptoms* a child displays would increase the number of *children receiving treatment at health facilities* for ARI. If a *child is present at the health facility*, then his/her immunization status may be checked and any missing *vaccination(s)* may be identified and addressed (R4b pathway). Alternatively, a direct relationship is depicted between the *decision to go to health facilities* for services and a *child present at a health facility for treatment of ARI*. This implies a link between habitual health-service-seeking behaviors in *vaccination* and tendancy for health-service-seeking in *other areas*.

SS4 vaccination service readiness and vaccination outcome pathways

When all parts are put together, SS4 is centered on the dynamic between *mother's educational status* and *household wealth status* (Figure 20). Similar to findings in

Chapter 3, *education* and *wealth* appear to have a causal relationship with *vaccinated children*. *Education* and *wealth* as well as their influencers affect *vaccinated children* through pathways involving women's *decision-making* and *availability* to seek health services, serving as the underpinnings of the *demand* and *vaccinated children* causal pathways that have been explored in the other subsystem CLDs. SS4 includes many *green* variables largely because of the connection between the series of steps in v*accine demand*-centered causal loops and contextual factors. Links between health-seeking behaviors for different types of care (prophylactic and therapeutic) indicate the health seeking patterns or habits that could reinforce service utilization among mothers and within households.

4.5 Discussion

Across the CLDs, demand-side and supply-side actors are a unifying theme. Each of the subsystems except SS2 include a point of intersection between supply and demand that involves human actors in the routine immunization system (e.g. *facility stockouts* experienced by parents seeking vaccination in SS1, health worker *motivation* affecting *technical quality* and *perceived quality* of service provision, etc.). These may be pivotal points in the system where a service is or is not received (or decision for a future service is or is not made).

The role of demand (the actions of *deciding to have children vaccinated* and *seeking vaccination at health facilities*) is a part of all but one of the subsystems. For such a clear role in the immunization system, *demand* is difficult to define and measure (informal Working Group on Vaccine Demand, 2015), and it is often viewed as a factor external to the immunization program (i.e. the balancing factor to immunization-supplied services). A better understanding of its role in the immunization system may be an opportunity for future research and improving immunization outcomes.

In SS1, availability of *vaccines at health facilities* appears to be one of the most influential components affecting *vaccination status of children*. The loops that factor into *vaccines at health facilities* are likely vulnerable to delays in the Afghan system (as well as systems in low-resource, politically unstable environments). *Vaccines at health facilities* determine whether vaccines are available for further outreach efforts to also increase vaccination events. *Vaccine management* could be a mediating component of *vaccine stock availability*, whether enough is received through the higher level cold chain, vaccines are stored correctly at facilities, identification of a need for more vaccines, and subsequent procurement of more vaccines.

Figure 21 presents a reduced version of SS1, highlighting the balancing feedback loop that includes cold chain capacity and viable vaccine stock (two variables that can be developed using the NHSPA data). *Demand*, affecting the potential *gap* between need and *vaccine availability*, is the only other *green* variable left in the reduced model not only drains the *vaccine stock* but also contributes to *vaccination*. This model is further simplified (Figure 25) where a *cold chain capacity* variable is used to replace the combination of *stock movement* and *good vaccine management* in the reduced model. This is because of empirical data availability that includes cold chain capacity measures (storage, transport, log keeping, etc.) at health facilities (as discussed in Chapter 3). The link between *vaccine stock at health facilities* and *vaccinated children* is reduced to one positive link (Figure 25), which is the case for each of the three original pathways connecting these two variables in Figure 21.

In SS2, the role *of laboratory capacity at health facilities* in immunization status required use of additional, higher-level variables such as *awareness among local authorities* and *advocacy* for surveillance among global partners that link laboratory capacity and surveillance to funding and support for basic laboratory capacity in the country. Without some inclusion of governance- and oversight-related components, it was difficult to hypothesis any loops in the routine immunization system that link laboratory capacity indirectly to vaccination service delivery. This subsystem was difficult for experts from the validation stage to reconcile with their experience in creating and strengthening immunization programs in low- and middle-income countries. Two experts stated that while surveillance is important, assessment of laboratory and surveillance performance in countries is a separate activity (separate from EPI reviews). Each of the loops in SS2 are reinforcing, and this may be a limitation of the available knowledge to-date. Laboratories and surveillance are considered important to support and strengthen immunization programs (Hotchkiss, Eisele, Djibuti, Silvestre, & Rukhadze, 2006; WHO, 2011b). Our results (Chapter 3) also suggest a significant association between improvements in laboratory capacity and improved immunization performance, but potential negative effects as well as pathways through which laboratory and surveillance capacity affect immunization performance are unknown. SS2 is reduced (Figure 22) to two loops, and our data include a *laboratory capacity* measure.

In SS3, the structure centers on the demand-maternal health service loop variations (e.g. *demand: decision…, demand: vaccination-seekers, health worker workload, SBA or ANC)* as well as the demand-vaccination loop variations (e.g. *demand: decision…, demand: vaccination-seekers, health worker workload*, *vaccine service* *capacity [availability]*, *technical quality…*, *vaccinated children*). Two loops further contribute to *vaccine service capacity [availability]* when considering health workers: the number of health workers and the stock of their knowledge and skills. Reducing SS3 results in vaccination-demand and SBA/ANC-demand loops are balanced by reinforcing and balancing loops for *health worker numbers* and *knowledge and skills* at health facilities. Figure 23 simplifies by combining *health worker counts* and the stock of *knowledge and skills* into one *health worker capacity* variable affected by *training* (Figure 25). *Good vaccine management* was changed to *cold chain capacity* to match the reduction of Figure 20 for the same reasons.

Because SS4 contains demand-loops from other subsystems, the CLD (Figure 20) was reduced (Figure 24) to the *education* and *wealth status* reinforcing loop and its relationship to *demand*. *Education* and *wealth status* appear to drive the demand loop that is also depicted in SS3 and partially depicted in SS1 (no immunization or maternal health service outcomes). The simplification of the reduced model (Figure 25) shows only *education, wealth status*, and *distance to nearest health facility* factors that affect *demand*.

According to the four CLDs, *vaccination service provision capacity [availability of services]* is most proximally affected by: the amount of *viable vaccine stock at facilities* through channels of *good vaccine management* and amply functioning *cold chains, viable vaccine stock in communities for outreach* through outreach capacity, *health worker knowledge and skill base at facilities,* the *number of health workers at facilities* (*including laboratory technicians*) through *health worker workloads,* and *service adaptation* to improve availability. Non-immunization outcomes are most proximally affected by technical and perceived quality of care as well as population characteristics, including demand and common individual and household health-seeking behaviors.

When reduced models were combined, the immunization system contained mostly reinforcing loops. Theoretically, one small improvement should vastly improve the immunization over time; oppositely, one small negative effect will devastate the system. This system structure may have an effect on the parameterization of future SD models. Though the original four subsystem CLDs (Figures 8, 9, 16, and 20) were extensively reduced and simplified, the final working model (Figure 26) still contains components for which there are no specific measures from empirical data (i.e. *health worker workload*, *demand*, and *health worker knowledge and skills* stock) though proxies may be developed. This has implications for knowledge and measurement gaps for not only the Afghanistan context but other developing countries as well.

4.5.1 Challenges and limitations

CLDs are commonly developed in collaboration with experts together in the same room over a series of iterations and improvements. This approach is especially useful when engaging with decision-makers and practitioners. Given time, location, and data limitations, the approach presented in this manuscript was designed to facilitate several CLD iterations. This may have limited the amount of local context-focused discussions and subsequent revisions. The approach may have also (likely) limited expert ownership of the CLDs, making the diagrams more vulnerable to external criticisms.

When soliciting feedback during the validation process, most experts wanted to talk through the diagrams rather than or before providing written feedback. It was difficult to balance the layout of forms for collecting validation information (as short as possible but still over ten pages of material) with providing enough useful information to orient reviewers to a new tool (the CLDs). Though a learning component was required, experts were generous with time and comments to strengthen the mental models. Most requested a verbal introduction to CLDs and the research question(s), which included time for questions and clarification on their understanding of CLDs in general.

Investigators who developed the CLDs and experts who reviewed them had the tendency to continue adding components to subsystems rather than parsing and making them more concise. This common practice dilutes their focus and potentially their relevancy, similar to adding too many variables to regression models or causal mechanism-focused diagrams in epidemiology. The end goal of the process was not to have perfect CLDs but rather to have workable subsystem models that could serve as a basis for SD models. For example, more information about the movement of vaccine stocks (through a functioning cold chain) could help to identify bottlenecks and causes of potential vaccine stockouts at lower levels of service delivery. Data for the present study, however, were limited to facility-based assessments of cold chain functionality.

Data availability affected component selection and CLD development, and this is mostly shown in the Discussion section where a reducing and simplifying process is shown in order to present a workable model for Chapter 5 SD modeling. Key components were first assigned to subsystems based on available empirical data and findings from preliminary immunization subsystem-focused regression models in Chapter 3. By limiting components based on future data needs, we may have limited necessary components for describing the context and causal pathways in the system. However, experts highlighted critical points in subsystems where components could be added or emphasized by pathways based on their knowledge and experience. This included the addition of latent components where limited empirical data are available.

Additional factors that describe processes and context (e.g. identifying demand-supply gaps, ordering more vaccines, good vaccine management, or vaccine stocks and parents' response to these events in SS1; women's status in society, father's educational status, and service adaptation in SS4; etc.) were included in subsystems despite not having empirical data to support their measurement and inclusion in SD modeling because of their signified importance in literature or by experts. In Figure 26, country-specificity may be lost because of not having measures for variables like women's status in society (and in the household) or male in the household is available to accompany mother to the health facility. But the macro-level system structure should still have remained intact for conceptually mapping the Afghanistan health system, and SD models in Chapter 5 will be populated using data from Afghanistan.

We were able to explore segments of the full system by subdividing the immunization system, making it difficult to link behavior across the subsystems. We gave careful attention to ensure that the *green* variables linked across the subsystems in a logical manner. At first glance many of the *green* variables may link what appear to be unrelated elements of an immunization system; for example, *health worker knowledge and skill base at facilities* and *technical quality of care* are explored in relationship to *basic laboratory capacity* and *surveillance* in SS2 as well as implied referrals across statuses of *vaccinated children* and *tetanus toxoid vaccination* of pregnant women in SS3.

Most of the experts consulted in this study considered SS2 a difficult CLD to interpret. The first two iterations used reinforcing pathways from *facility basic laboratory capacity* passing through changes in *health worker awareness* via *improved infectious disease surveillance*. Expert feedback emphasized that SS2 could instead focus on the relationship between *facility basic laboratory capacity* and *local authorities* (their support, awareness, advocacy, etc.). Some experts were uncertain of a direct link between *facility basic laboratory capacity* and *vaccinated children*. In preliminary secondary data analyses, basic vaccine laboratory capacity scores were persistently statistically significant factors of Penta3 coverage (Chapter 3). *Technical quality of service provision* and *health worker knowledge and skill base* at facilities were critical for linking system laboratory and surveillance capacities to immunization outcomes. Because of improving efforts for building laboratory and surveillance capacity in countries, the feedback mechanism of *facility basic laboratory capacity* required expanding boundaries past the country system to include *global advocacy, funding,* and *resources* that affect *national, regional,* and *facility laboratory capacities*. This is an example of the extensiveness of system behavior where causal links are not only linear and do not occur in isolated pathways.

4.6 Conclusions

Pathways that include *demand* for vaccination and the intersection of supply-demand are supporting three of the four immunization subsystems. While vaccine stocks at health facilities are important for vaccination provision, vaccine management likely mediates its effect. The pathways through which basic laboratory capacity at health facilities and bolstered vaccine-preventable disease surveillance affect immunization can be mapped at higher levels (e.g. governance), but less is known at lower levels of service delivery or in the population. and non-immunization service outcomes. This paper presents the process of developing causal loop diagrams and their interpretation as a method that captures the complexity, causal pathways, and feedback behavior of the objects of study in health systems research: systems and subsystems. Such research designs and approaches may contribute to further developing the methodological and funding paradigm not only in health systems research but also in public health research.

4.7 Recommendations

Findings suggest that better understanding of demand and demand-side factors and their role in immunization systems is pertinent. Moreover, where and how demand intersects with supply in the immunization system is critical for understanding causal pathways at lower levels of service delivery. Measures for demand (and immunization system actor behaviors) may be an area of concentration for future research efforts, which will contribute to the knowledge and measurement gap in global immunization. More research is needed to understand the role of laboratories and surveillance in immunization programs and immunization service outcomes, again, particularly at lower levels of the immunization system. Because of the constraints on data availability, efforts to identify and/or collect data on cultural, environmental, or political factors would support case studies similar to the one presented in this paper. It may be that other methods like historical policy reviews or key informant interviews can be used to create measures that supplement empirical data collected by surveys for leading to future systems modeling. Studies such as the one presented in this paper offer first glances at systems and may require less time and fewer resources to understand system structure.

4.8 Chapter 4 Tables and Figures

Table 13. Organization of subsystems: connector (green) variables as well as immunization and non-immunization outcome(s) of interest

	Subsystem (SS)			
Variable name	SS1	SS2	SS3	SS4
Connector (green) variables				
Good vaccine management	x		x	
Demand: children at facility for vaccination	x		x	x
Demand: decision to go to facility (for health services)	x		x	x
Vaccination service provision capacity [availability] at facilities	x		x	x
Vaccination service provision capacity [availability] for outreach	x		x	
Outreach activities	x		x	
Technical quality of service provision		x	x	x
Perceived quality of service provision			x	x
Community trust in system			x	x
Health worker knowledge and skill base at facilities		x	x	
Immunization outcome (green) variable of interest				
Vaccinated children	x			x
Non-immunization outcome (red) variables of interest				
ANC visits (pregnant women receiving antenatal care)			x	x
Skilled birth attendant at deliveries			x	
Tetanus toxoid vaccination of pregnant women			x	
Demand: child at facility for treatment of illness				x

Table 14. The conceptual mapping of system dynamics and the types of feedback behavior in four subsystems of the immunization system in Afghanistan using causal loop diagrams (CLDs)

Subsystem	Subsystem focus	Types of feedback	Full model Figure number
1	Cold chain and vaccine stock	3 reinforcing and 3 balancing feedback loops; 1 loop variation	7
2	Basic, vaccine-related laboratory capacity at health facilities	3 reinforcing feedback loops; 5 loop variations	8
3	Health workers and their knowledge, skills, and experience	1 reinforcing and 4 balancing feedback loops; each loop has 1 or more loop variations except B4	15
4	Household and women's characteristics	4 reinforcing and 1 balancing feedback loops; 2 variations	19

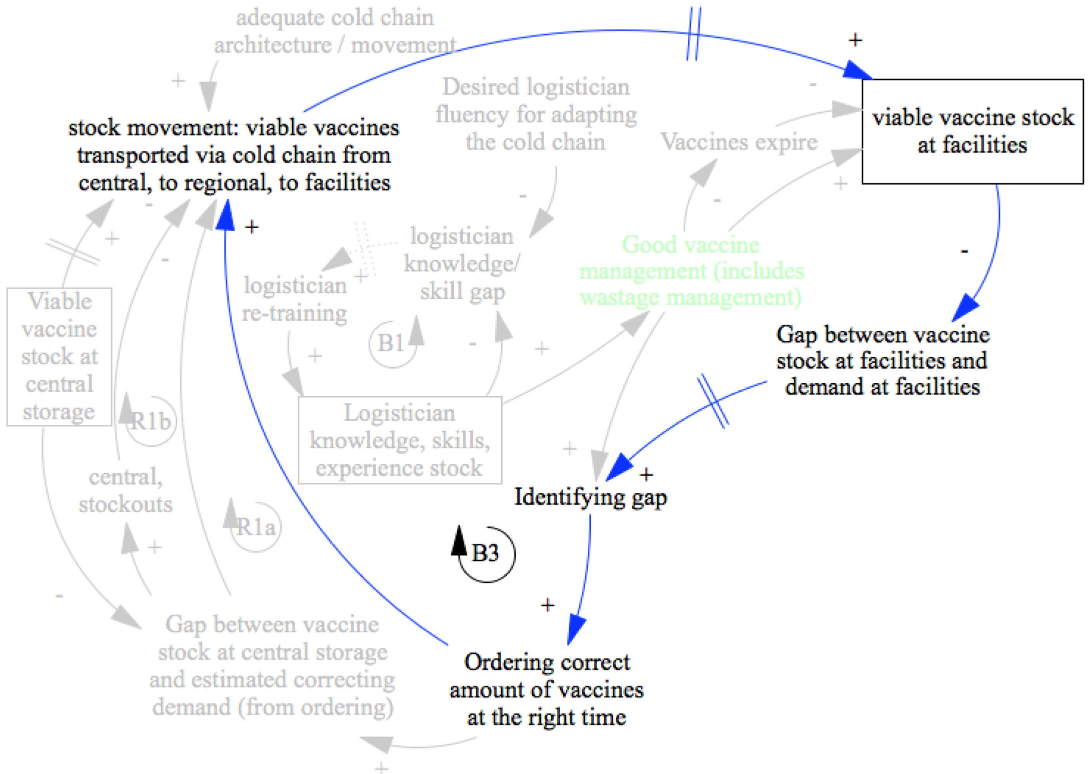


Figure 5. Subsystem 1: Balancing loop three (B3). Basic supply and demand of vaccine stock, balanced through reordering

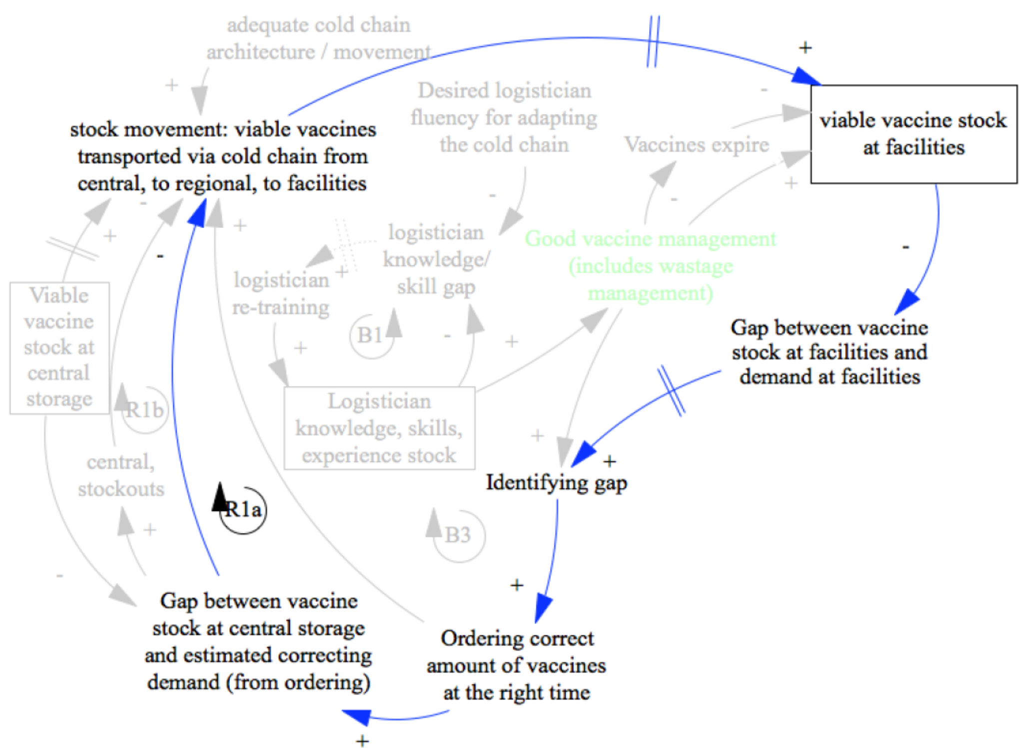


Figure 6. Subsystem 1: Reinforcing loop 1a (R1a). Improved overall flow of vaccines du to reducing two potential supply-demand gaps]

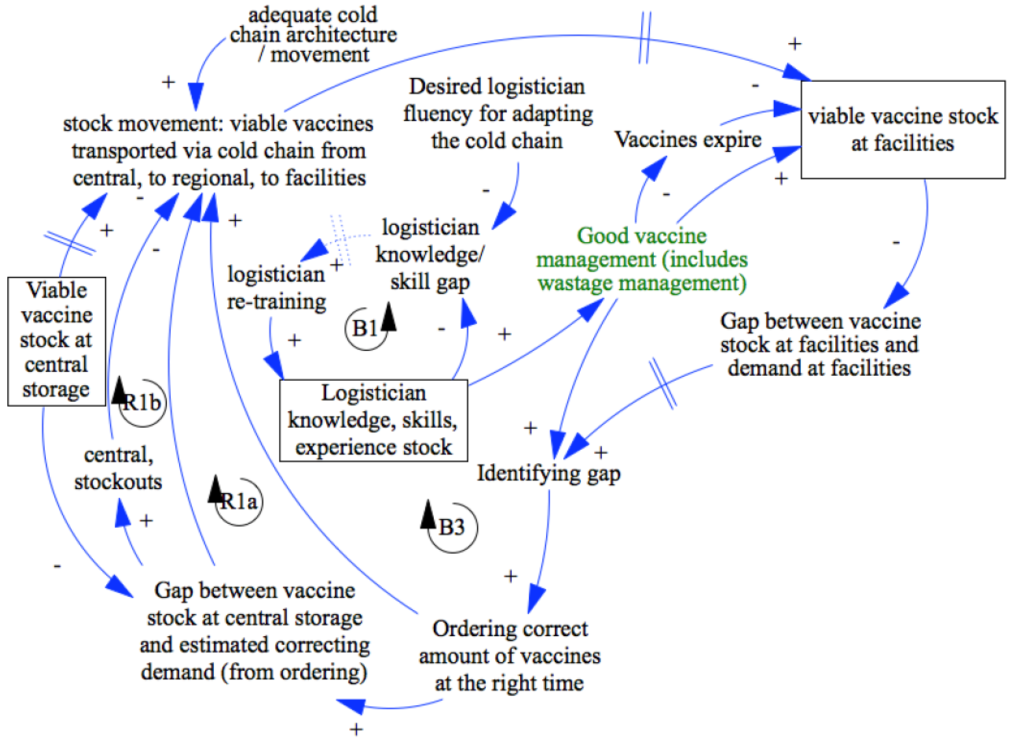


Figure 7. Subsystem 1: Balancing loop B1 influence on B3 and R1a-b. Logistician knowledge, skills, and experience stock

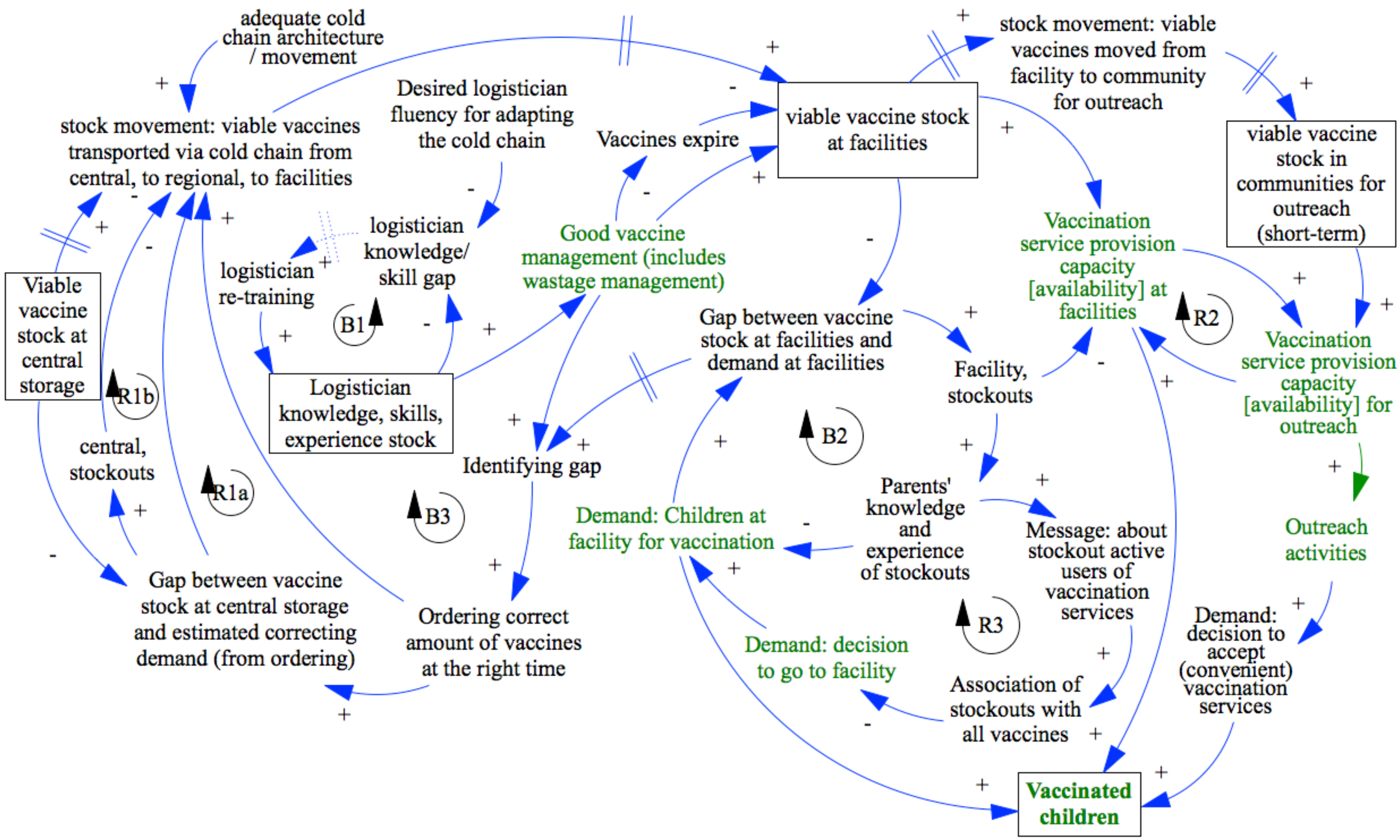


Figure 8. Subsystem 1, full: Exploring the dynamics involved in cold chain functionality and stock inventory and their relationship to vaccination coverage

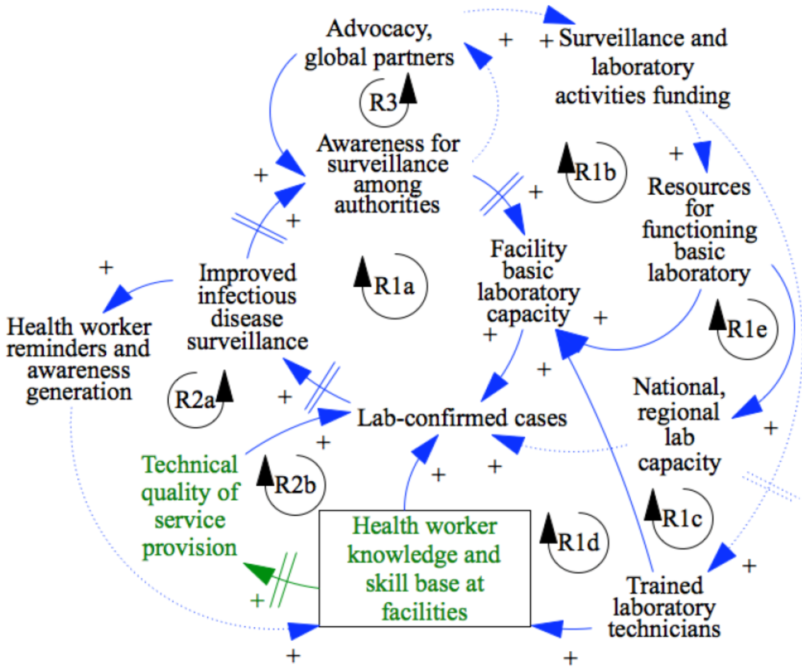


Figure 9. Subsystem 2, full: Exploring the dynamics involved in basic vaccine-related laboratory capacity and its relationship to vaccination coverage

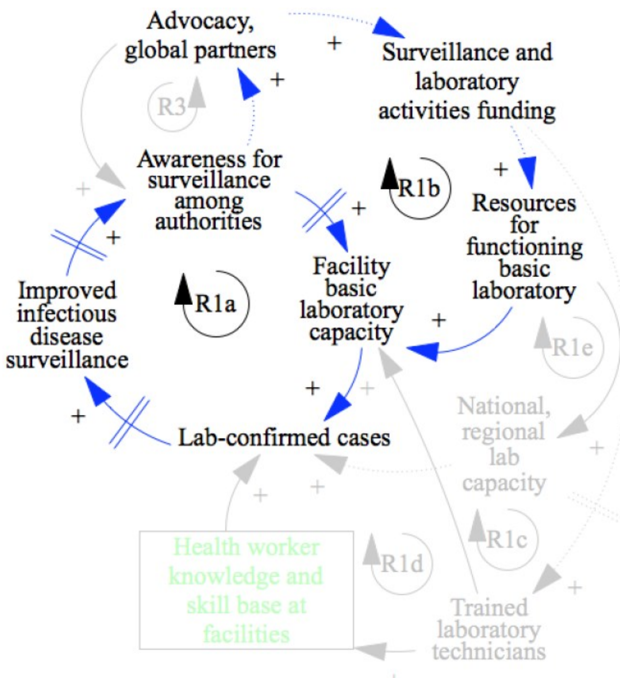


Figure 10. Subsystem 2: R1a and R1b loop variations. Basic laboratory capacity at facilities, improved surveillance, and improved awareness and support

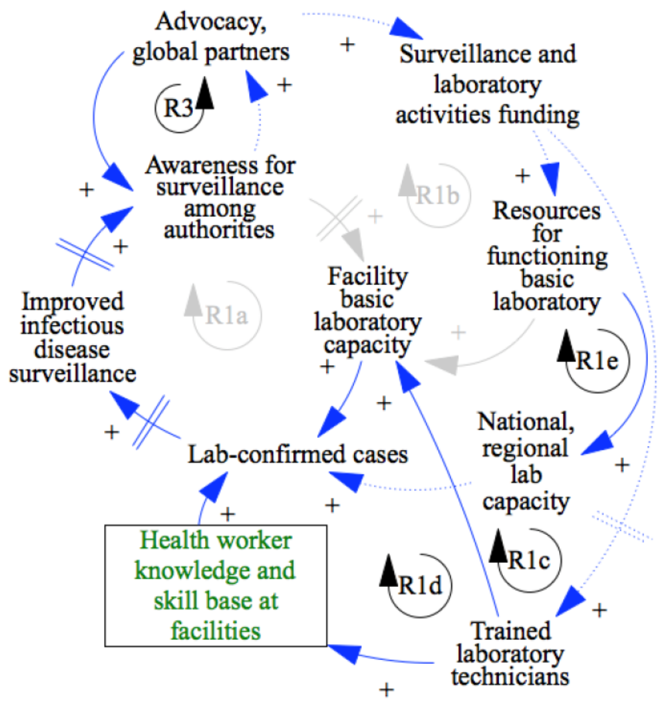


Figure 11. Subsystem 2: R1c-e and R3. Variations of the R1 loop that include aspects of health worker knowledge and training and the dynamic between awareness and advocacy

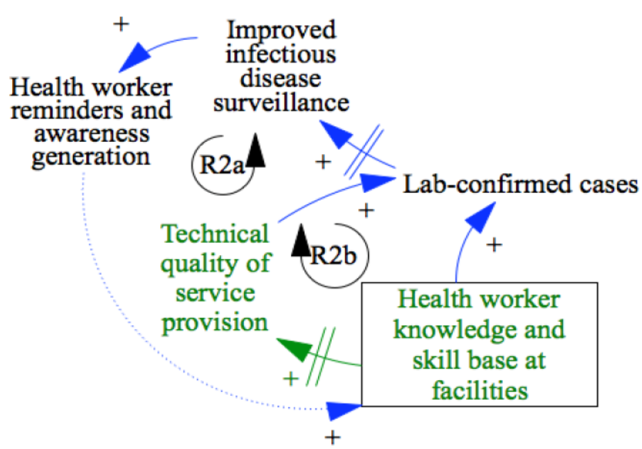


Figure 12. Subsystem 2: R2a and b. Laboratory capacity, surveillance, and health workers

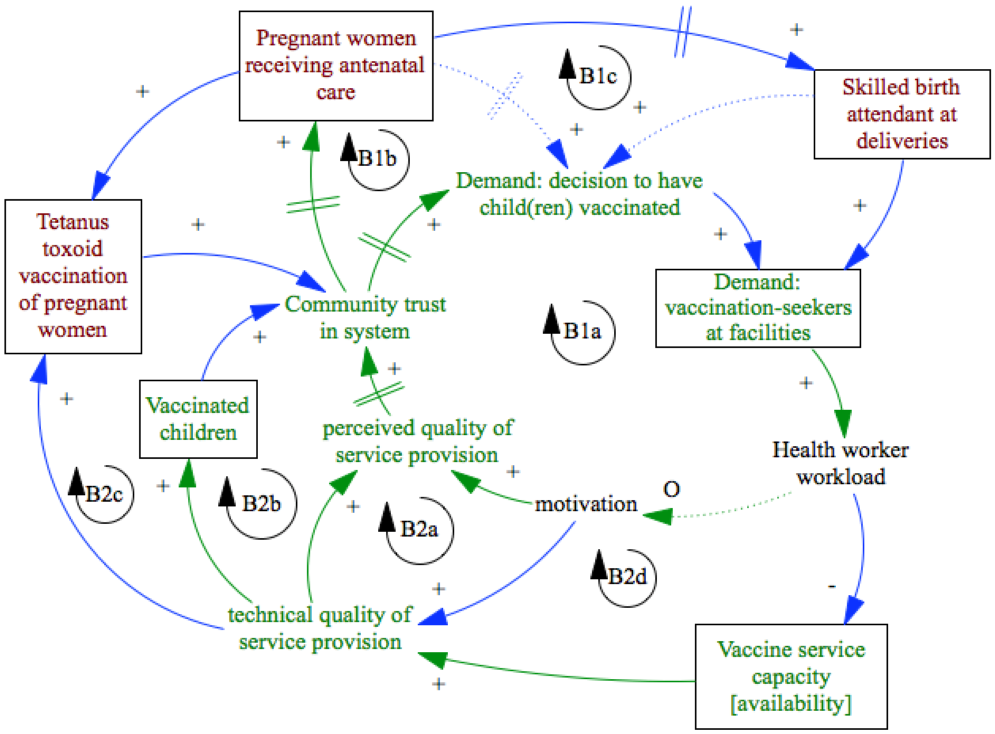


Figure 13. Subsystem 3: B1 and B2 loop variations. Demand for vaccination, quality of care, and immunization- and non-immunization-related outcomes

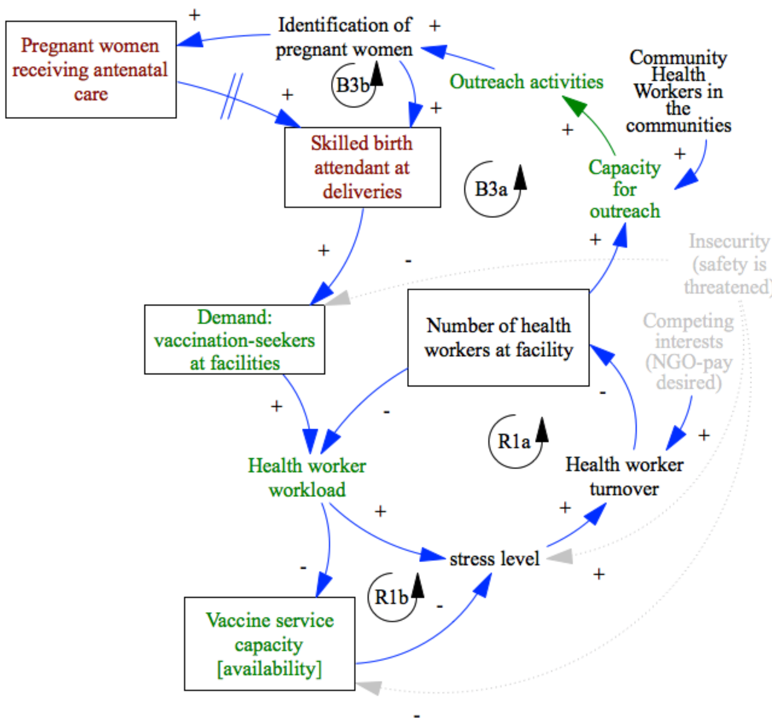


Figure 14. Subsystem 3: B3 and R1 loop variations. Demand for vaccination, number of health workers, immunization outreach activities, and non-immunization-related outcomes

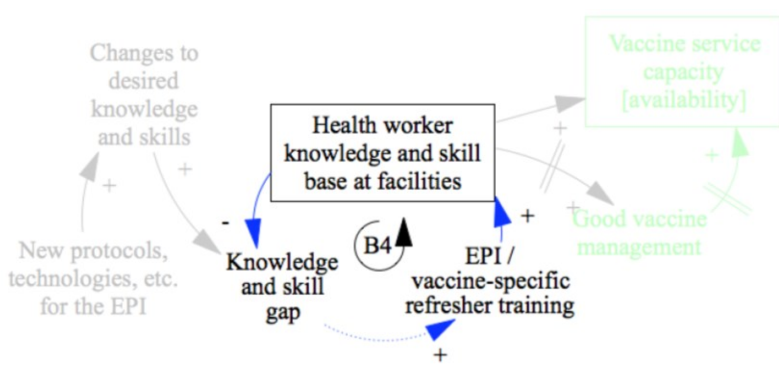


Figure 15. Subsystem 3: B4 loop. Health worker knowledge and skill base at facilities

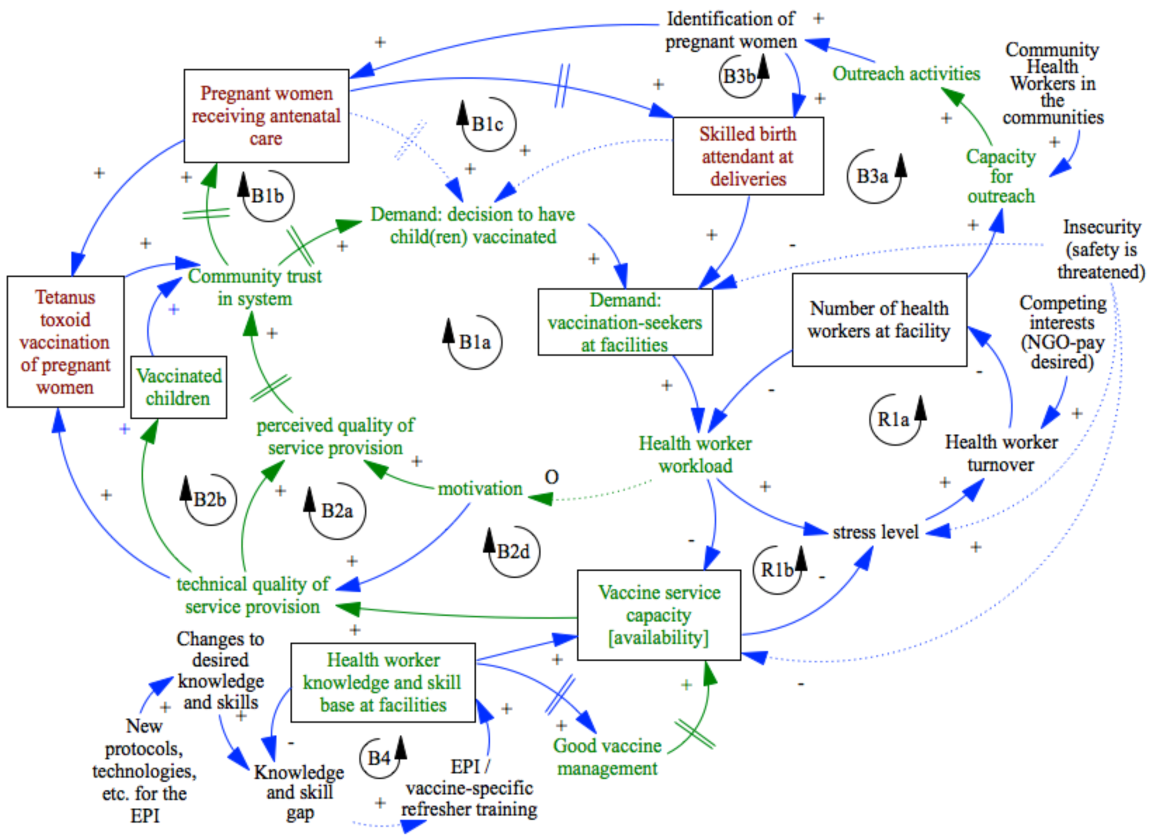


Figure 16. Subsystem 3: full. Exploring the dynamics involved in health workers and their knowledge, skills, and experience and their relationship to vaccination coverage

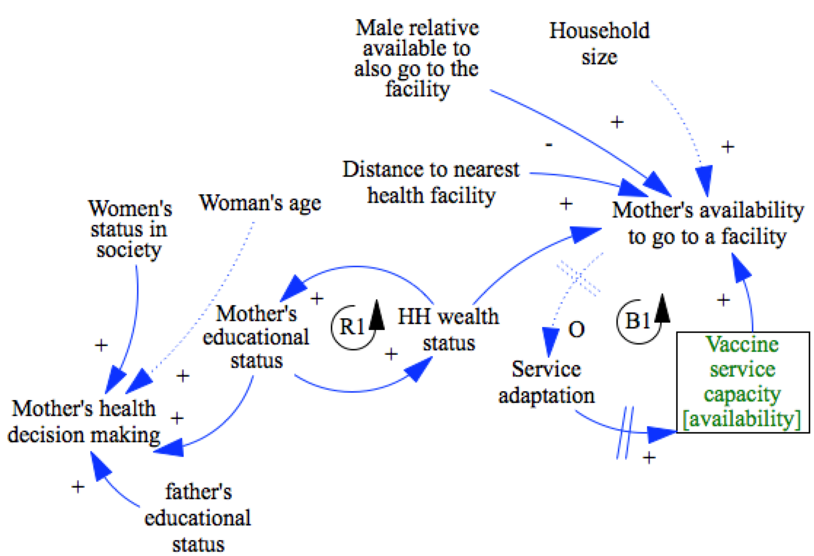


Figure 17. Subsystem 4: R1 and B1 loops. Mother's educational status and household wealth status and their relationship to vaccination demand

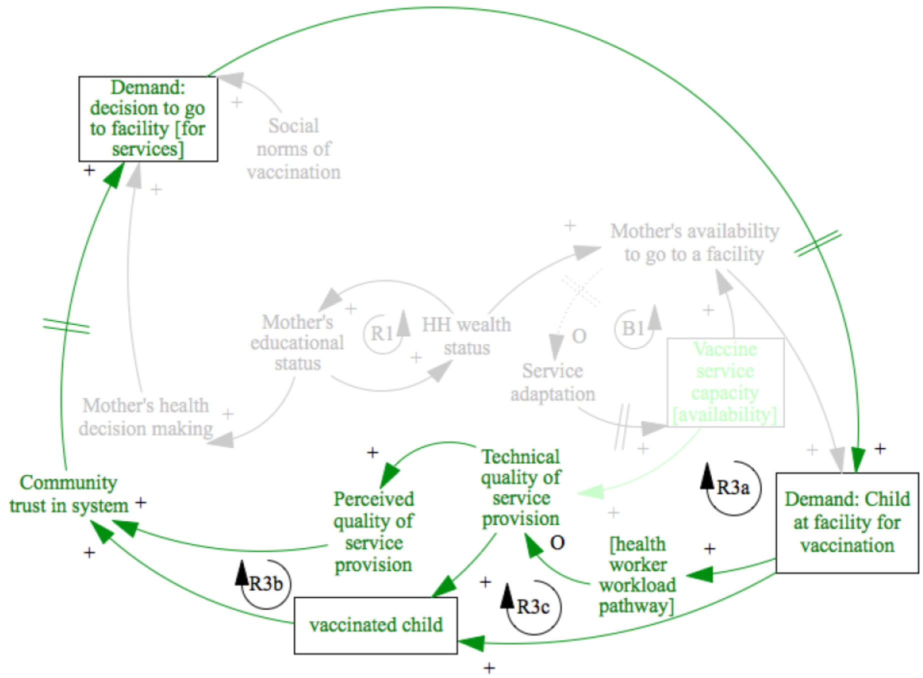


Figure 18. Subsystem 4: Loop R3 variations. Mother's educational status and household wealth status and their relationship to vaccination demand

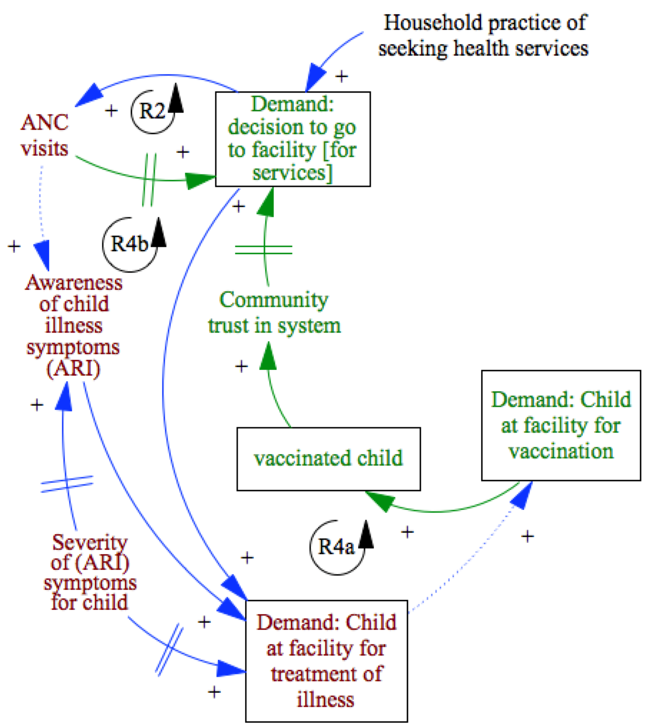


Figure 19. Subsystem 4: Loop R2 and R4 variations. Introducing treatment of Acute Respiratory Illness (ARI) treatment

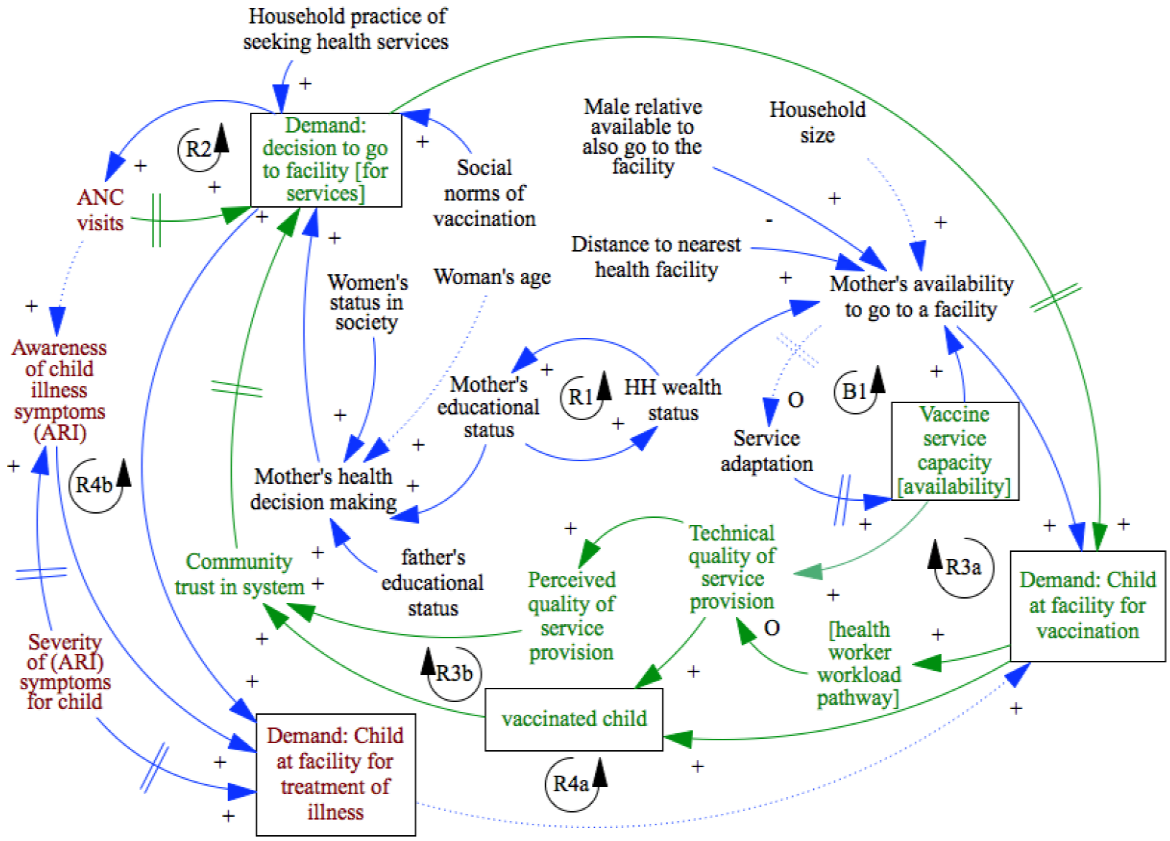


Figure 20. Subsystem 4: full. Household and women's characteristics

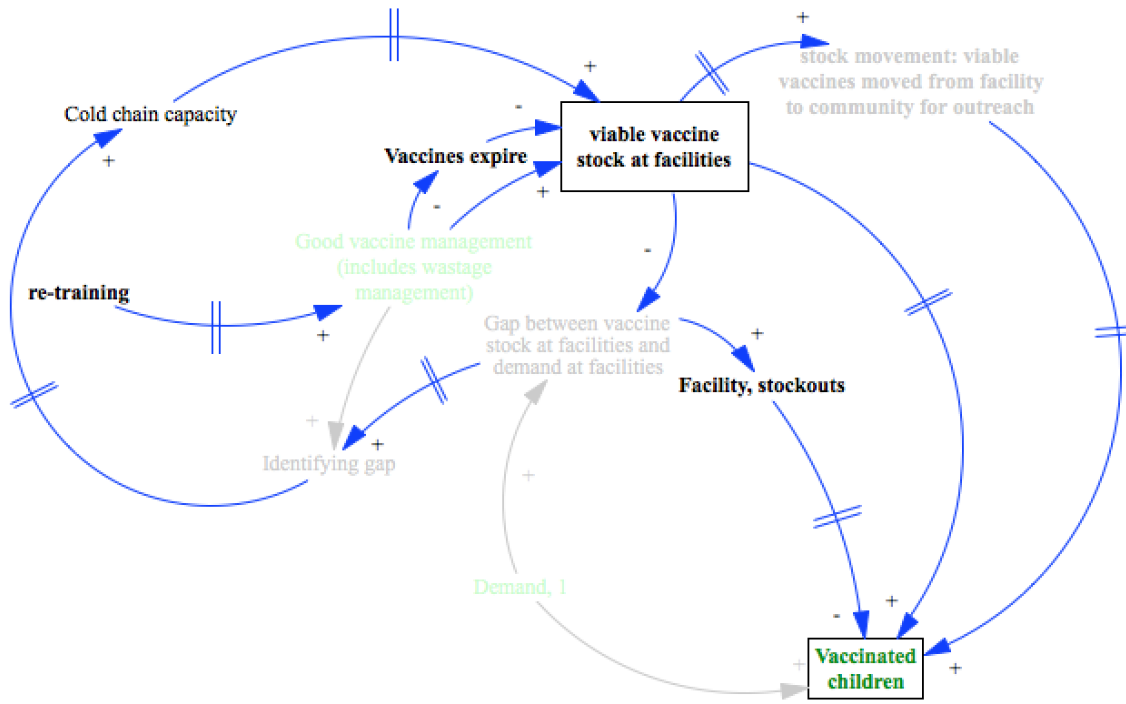


Figure 21. Subsystem 1: reduced from Figure 8 (full system) showing components with available empirical data (bold) and connections

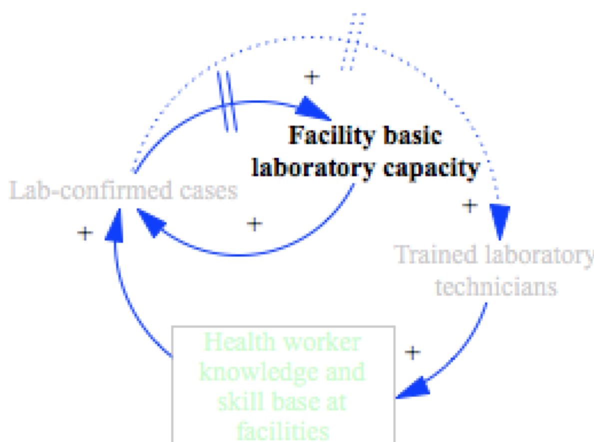


Figure 22. Subsystem 2: reduced from Figure 9 (full system) showing components with available empirical data (bold) and connections

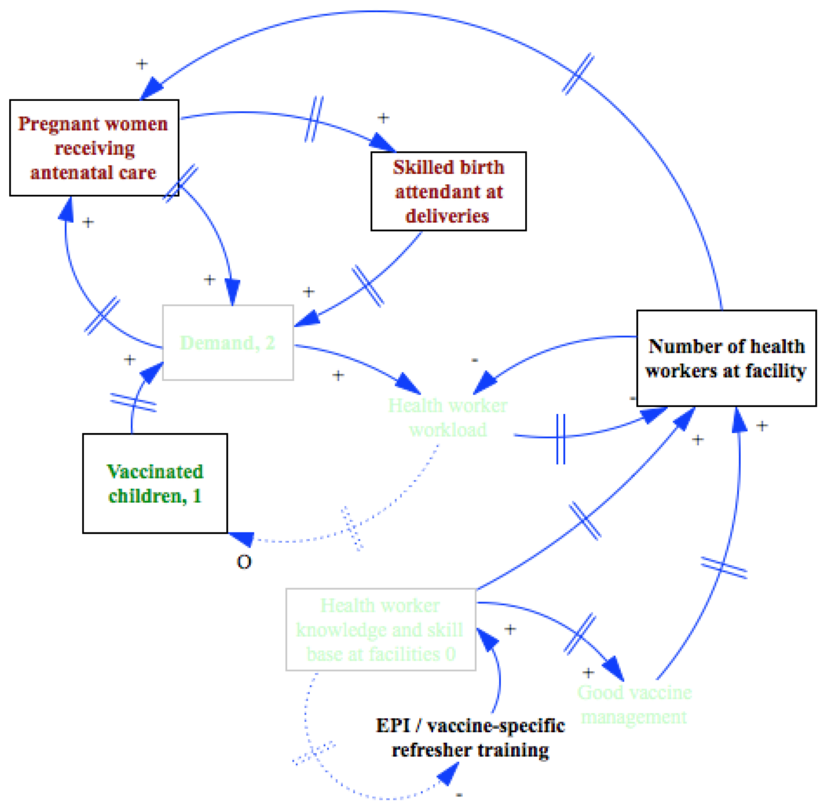


Figure 23. Subsystem 3: reduced from Figure 16 (full system) showing components with available empirical data (bold) and connections

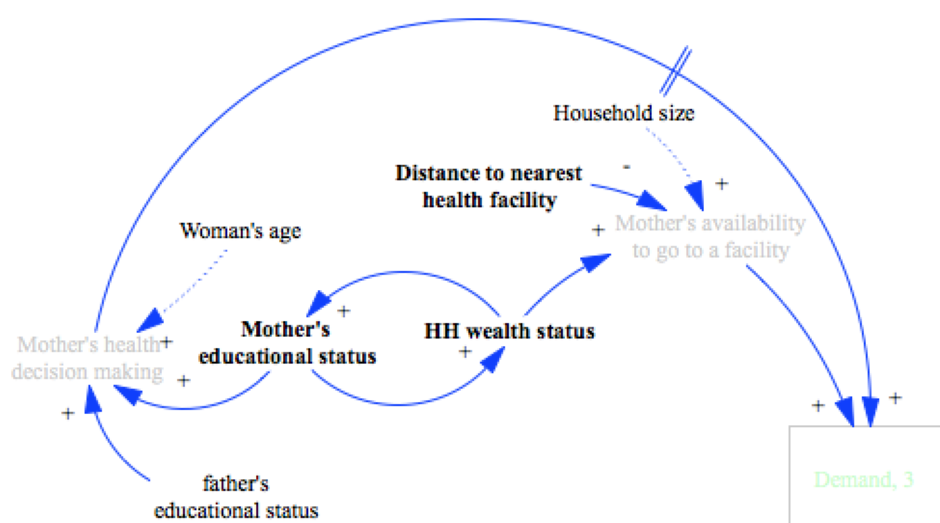


Figure 24. Subsystem 4: reduced from Figure 20 (full system) showing components with available empirical data (bold) and connections

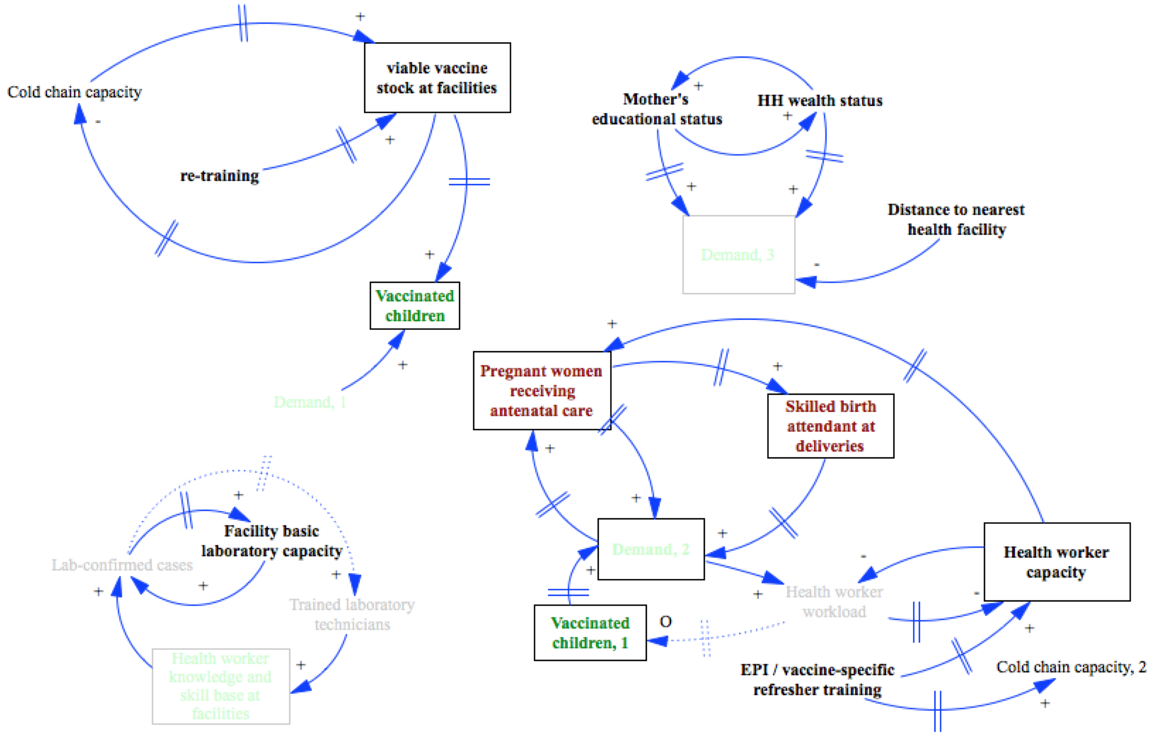


Figure 25. Reduced subsystems 1-4: preparing for merge

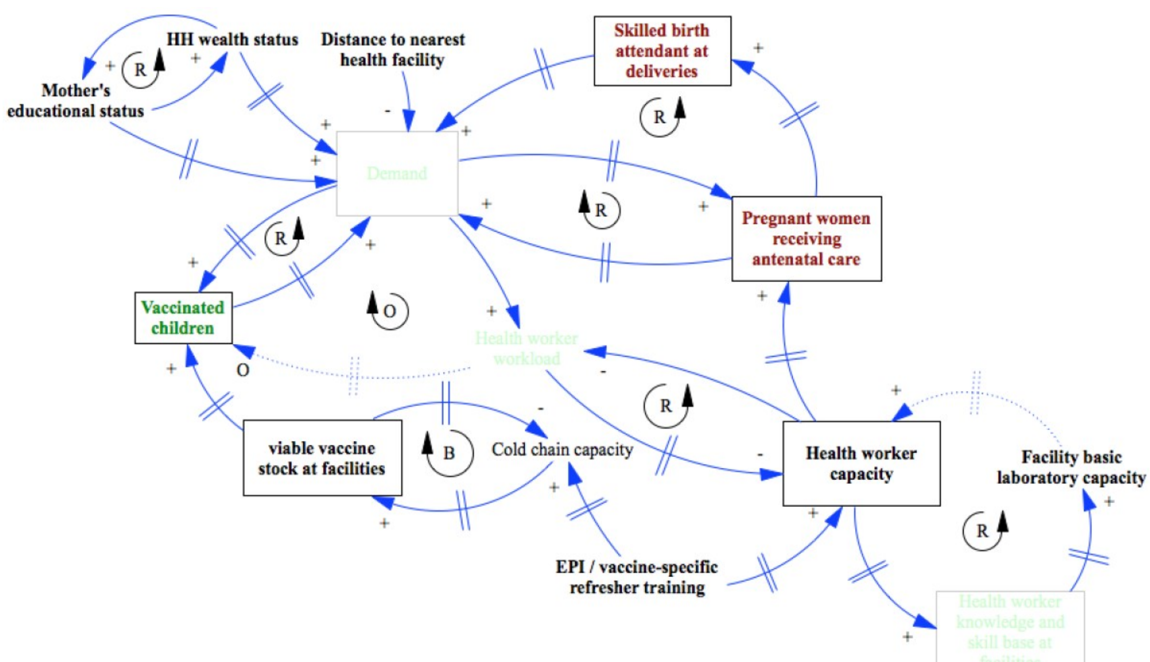


Figure 26. Immunization system in Afghanistan: combination of subsystems 1-4, accounting for empirical data availability. In preparation for system dynamics modeling (Chapter 5)

Intended to be blank.

Chapter 5. A system structure confirmatory exercise using system dynamics modeling: examining anticipated impact of immunization system readiness components on immunization and maternal health service outcomes in the Afghan health system (Paper 3)

Abstract

Background. Health systems are complex and adaptive, and their behavior can be misunderstood if their dynamism is overlooked. The purpose of this study is to investigate the dynamics of immunization systems in their host health systems by examining *immunization system readiness* components and their anticipated year-to-year impact on *immunization and maternal health services outcomes* in Afghanistan between 2007-08 and 2012-13.

Methods. System Dynamics (SD) modeling was used for a model confirmation exercise of the immunization system in Afghanistan. Secondary data from facility- and population-based surveys were used to populate and parameterize the model. The SD model was developed based on a series of causal loop diagrams that serve as conceptual frameworks for the components and construction of the model. Model parameterization was completed using data from past facility- and population-based surveys in Afghanistan. The model was created across four subsystems that connect and interact: cold chain functionality and stock performance, basic laboratory capacity, human resources and information/motivation stocks, and demand-side factors.

Findings. The year-to-year impact of health worker capacity on antenatal care (ANC) coverage was a -1.65 percentage-point change (SE: 0.93). Both ANC coverage and demand-side factors affected coverage of skilled birth attendants at deliveries (-0.105 (SE: 0.02) and 0.52 (SE: 0.17) year-to-year percentage-point changes, respectively). No components statistically significantly affected immunization coverage. The overall year-to-year change in ANC and immunization coverage were 7.64 (SE: 0.65) and 1.77 (SE: 0.86) percentage-point improvements, respectively. These overall year-to-year changes

mimic historical year-to-year trends in ANC and immunization coverage in Afghanistan. Immunization system readiness components were found for the most part to negatively affect their future measures, which may relate to reinforcing feedback loop-driven behavior and/or the limitations of year-to-year resiliency in these system readiness measurements.

Conclusion. Models such as the base SD model can be used to confirm mental models of system structure and their behavior using data that may already be available. Those models can also be used for policy exploratory exercises to identify efficient points of intervention in the system to test candidate interventions for their potential impact on immunization and maternal health outcomes in the Afghanistan routine immunization system.

5.1 Introduction

Childhood vaccination is credited as one of the most effective interventions in public health (Duclos et al., 2009). More than forty years ago in 1974, the WHO launched the EPI (Lim et al., 2008; Shen et al., 2014; WHO, 2011b). As a result of concerted international efforts, most low- and middle-income countries had developed national immunization programs based on the EPI scheme, and in 1990 UNICEF declared that global 80% coverage targets had been achieved (Lim et al., 2008). Since then, vaccination coverage has indicated that gains were stagnating or, worse, declining (Maekawa et al., 2007; Steinglass, 2013; WHO & SAGE, 2015). Programs have become increasingly complex since 1974 with rising costs, added vaccines in the routine schedule, hard-to-reach populations, increased demands on cold chain infrastructure and logistics, and exogenous threats like civil unrest and conflict (Shen et al., 2014). The relationship between immunization systems and their host health systems is of growing concern among experts who emphasize the crucial links and possible tradeoffs between immunization and non-immunization performance.

5.2 Background

A *system* is a set of "things", interconnected in such a way that they produce their own pattern of behavior over time, and the key to understanding their behavior is to examine their structure (Meadows DH, 2008). Accordingly, a *health system* is a set of components that are interconnected and designed with the intention of supporting desired health outcomes. An *immunization system* could similarly be defined but with the intention to support desired, immunization-specific outcomes. In order to understand the system's behavior, the structure and connections of the immunization system would need to be examined.

Routine immunization, defined as "the foundation through which countries provide access to lifesaving vaccines, aiming to control and eliminate threats of vaccine preventable diseases*"* (Shen et al., 2014) (see also in (Steinglass, 2013; WHO, 2011b)), is often portrayed as an integral part of a health system and represents a set of resources and activities that strengthen the health system. It also has a vertical nature due to its content- and intervention-specificity as well as vaccination campaign and eradication strategies that are intended to circumvent limitations of weakly structured immunization and health systems. Routine immunization has been described as a critical subsystem of the health system (Clements et al., 2011; Susan A Wang et al., 2012), a health service delivery platform from which other services may be provided (Sodha & Dietz, 2015; Steinglass, 2013); it has been characterized as both dependent upon and strengthening of the health systems through which services are delivered (Shen et al., 2014). In general, service delivery capacity, consistency, and reach are important to address under-vaccination issues whereas caregiver awareness, attitudes, and beliefs, as well as caregiver and household factors including health seeking behavior, are mostly linked to issues of non-vaccination (Bosch-Capblanch et al., 2012; Cappelen et al., 2010; Favin et al., 2012; Rainey et al., 2011; Shea, Andersson, & Henry, 2009).

5.2.1 Immunization system – health system relationship

Evidence suggests that focus on improving vertical programs and their outcomes improves access and uptake of the targeted health services (cite). Other hypothesized effects of focused efforts like through vertical programs are improved availability of essential supplies and drugs, replenished and strengthened health facilities, greater availability of qualified health personnel, improved capacity through in-service training, and increased demand and support for health services by the community partly through increase in the availability and accuracy of good quality health information (WHO-MPSCG, 2009). One commonly cited negative impact of vertical programs on health systems is distorted availability of resources across the health system (WHO-MPSCG, 2009).

The pathways through which immunization systems interact with their host health systems are just starting to be examined using methods that support accounting for *complexity*. *Complexity* is not merely the opposite of the descriptor *simple* but rather is a loosely defined and used term that indicates the importance of relationships and adaptive interactions of components in the emergence of the whole (system) (Greenwood-Lee et al., 2016). Evidence suggests that strong routine immunization platforms can generate policy and financing innovations for the health system (Lahariya, 2015; Shen et al., 2014; Tapia-Conyer et al., 2013). Immunization-specific logistics and cold chain subsystems can strengthen the movement of resources throughout the health system (Lahariya, 2015; Shen et al., 2014). Trained people working in the immunization system, particularly those skilled in management, logistics, surveillance, and regulation may bolster the healthcare workforce in the host health system, and the sheer number of required encounters with the health system throughout the immunization schedule represents opportunities to interact with parents, educate them on vaccines, and build rapport (Cappelen et al., 2010; Shen et al., 2014; Sodha & Dietz, 2015). It has been hypothesized that community engagement strategies for immunization could improve community ownership of health programs, build members' skills in planning, implementing, monitoring, and advocating, and foster environments for equity- and trust-building that permeate into generalized trust in other public services (Cappelen et al., 2010; Gilson et al., 2005; Ozawa et al., 2016; Ozawa & Stack, 2013; Shen et al., 2014; Varghese et al., 2014).

When pathways lead to other areas of service delivery, maternal health service systems could be acting synchronously with the immunization system. Whether the linked behavior produces positive or negative tradeoffs is less known. Health care seeking for mothers and children have been found to be similar (Cardol et al., 2005; Hu et al., 2013; McGlynn et al., 2015; Wado et al., 2014). A child's health is typically the immediate responsibility of mothers. Incomplete vaccination has been linked with non-use of maternal-child health services, living in conflict-affected areas, cancelled vaccination sessions, and missed opportunities for vaccination (Sodha & Dietz, 2015). Maternal health services have been linked to immunization services (Semwanga, Nakubulwa, & Adam, 2016) such as ANC, facility-based deliveries, and skilled birth attendance at deliveries (Babalola & Fatusi, 2009; McGlynn et al., 2015). In Afghanistan, the most common reasons given by women for not giving birth at a health facility were travel distance, lack of transport, transport costs, and not thinking skilled birth attendance was necessary (Tappis et al., 2016). Though the same study explored systems characteristics that were found not to significantly predict skilled birth attendance, investigators found access patterns of bypassing nearby health facilities for public or private hospitals farther away (about 50% of women who gave birth with a skilled attendant) or a nearby primary care facility for a different facility of a similar type (about 10%) (Tappis et al., 2016). In an analysis of 31 countries, Kruk and Prescott found that national and community factors, particularly health system characteristics, explained 66% of the variation in skilled birth attendance across countries (Kruk & Prescott, 2012), whereas more commonly cited individual and household factors linked to maternal health services (i.e. household wealth status, mother's educational status, and parity (Sodha & Dietz, 2015)) were found to explain only 16% (Kruk & Prescott, 2012).

5.2.2 SD modeling

SD models (see Section 1.7 for more SD background) have helped to make significant contributions to addressing epidemiological issues, issues of health care capacity, health care delivery, and patient flow management (J. B. Homer & Hirsch, 2006). To our knowledge, the only example specifically using SD modeling for examining the immunization sub-system as a whole comes from Rwashana and colleagues in Uganda (A. S. Rwashana et al., 2009; A. Rwashana & Williams, 2008). However, Rwashana and colleagues aimed to understand immunization healthcare problems as well as how to improve immunization coverage effectiveness through the development and simulation of a healthcare policy design model whereas the proposed study aims to understand the policy levers specifically associated with improved immunization that simultaneously produce positive spillover effects in other areas of the primary health care (PHC) system.

5.2.3 Study context

This study is the third and final part of a three-part *health subsystem-systems tradeoffs country case study*, which pairs a set of three methodologies to unpack the relationship between one particular subsystem (immunization) and its host health system (the Afghan health system). In *step one* we examined the relationship between immunization system readiness to deliver immunization services and immunization coverage outcomes in Afghanistan using marginal regression models (Chapter 3). In *step two* we undertook a literature- and expert-based CLD building exercise to identify the main feedback loops and causal pathways through which immunization system readiness may impact immunization and non-immunization performance in the Afghan health system (Chapter 4). The outcomes and process of *step one* informed *step two*; *step one* and *two* inform the third and final step.

5.3 Study objectives

This study aims primarily to provide a detailed example of the application of SD modeling (Hirsch, Levine, & Miller, 2007; J. B. Homer & Hirsch, 2006) in health policy and systems research. Secondly, we also aim to confirm the immunization system structure represented in the step-two (case study) CLDs (Chapter 4) and examine the anticipated impact of components on system behavior. Using these CLDs as well as findings from preliminary regression analyses (Chapter 3), this study uses SD modeling to simulate the impact of immunization service readiness on immunization and non-immunization performance in the Afghan health system. This is a model-confirmatory exercise, examining system structure and mechanisms that were previously conceptually mapped in the CLDs. The following research question was addressed by the present study:

1) What are the significant immunization system components and their anticipated year-to-year impact on immunization and maternal health service coverage in Afghanistan between 2007 and 2012?

The results of the SD models are intended to: 1) provide a succinct example of the utility of SD models in health policy and systems research using existing data sources, and 2) inform immunization practitioners, researchers, and policymakers on the effects of system structure on system behavior.

5.4 Methods

5.4.1 Information sources and system components

Data comes from the same three sources described in Chapter 3: the NHSPAs, the 2007-08 NRVA, and the 2012-13 AHS.

The immunization outcome of interest is the coverage estimate of the third dose of pentavalent vaccine among 12-23 month-old children (Penta3). Non-immunization outcomes of interest (for maternal health services) are coverage estimates of SBA during delivery and receipt of at least one ANC visit with a skilled provider during pregnancy among ever-married women age 12-49 years who have been pregnant with a live birth outcome in the past two years. Outcomes of interest were calculated using data from the 2007-08 NRVA and 2012-13 AHS.

We used the same immunization service readiness variables developed for the analysis in Chapter 3 (Appendix 1): a vaccine stock (including expired inventory), cold chain functionality, number of health workers who provide vaccination services, health workers who have had vaccine-specific refresher training, management agency type, and laboratory capacity for vaccine-related diagnostics and surveillance. An index was constructed using a mean score of multiple items for laboratory, stock, and cold chain readiness at facilities for each province across each year. An item was rated as 1 if it was available or in good condition or as 0 otherwise. Scores ranged from 0 to 100 and were averaged for each province and year combination. Basic laboratory capacity at health facilities was assessed by the ability to conduct the following tests: tuberculosis (TB) smears, malaria smears, rapid malaria, liver function, hepatitis B, and gram. Vaccine stock at facilities was assessed by an inventory (present and viable, present and expired, etc.) of the following vaccines: Bacillus Calmette-Guérin vaccine for TB; oral polio vaccine (OPV) for polio; pentavalent vaccine (PENTA3) for diphtheria, pertussis, tetanus, hepatitis B, and Haemophilus influenza type B (Hib); measles vaccine; and tetanus toxoid vaccine. Cold chain functionality was determined based on storage and transportation components inventoried at each facility such as a refrigerator, ice/transfer box, power source, temperature log, etc.

Health worker capacity scores were calculated using principal component analysis (PCA) using information on average health worker counts (vaccinators, physicians practicing obstetrics and gynecology, nurses, midlevel clinicians, and general physicians). A second health worker capacity (training, community reach, and management focused) PCA score was developed using the percentage of health workers having received vaccine-specific refresher training, percentage of health facilities that have the immunization schedule posted in the building, and the percentage of women age 12-49 years who knew of CHWs in their community and agreed that CHWs provide useful services. PCA was used to create a *demand-side factors* component using percentage of poorest, middle, and richest households, percentage of mothers who have ever had a formal education, percentage of households that live within two hours from the nearest health facility, percentage of currently married women age 12-49 years who currently use a form of modern contraceptives (includes female sterilization, intra-uterine device, contraceptive pill, contraceptive injection, and condom), and percentage of ever-breastfed children born in the two years prior to the survey (survived or dead) to ever-married women age 12-49 years. System components, stock and flow diagram labels, and component descriptions are provided in Table 16.

5.4.2 Model building

Using Vensim PLE 6.4 (VentanaSystems, 2015) to develop a stock and flow diagram, a visual representation of the SD model was developed, referring to CLDs on Afghanistan immunization system (Chapter 4). Boxes in the model represent *stocks* (quantities) of different forms of system readiness as well as coverage of different health services that change over time. Double-lined arrows represent *inflows* or *outflows* (rates) that change the level of *stocks,* and each *flow* is regulated by a valve (double, stacked triangles). Single arrows represent *parameters* that affect *flows*, and variables with no box represent *auxiliaries* (constants) that affect flows. *Stocks* of system readiness and coverage outcomes change from year to year according to different model parameters, indicating that the model is dynamic. Using this setup, the flow of system readiness and coverage outcomes can be visually depicted. Feedback loops were label as 'R' or 'B' for their reinforcing or balancing nature (A. S. Rwashana et al., 2009), and loops were numbered for cataloging purposes.

5.4.3 Base SD model

In order to continue with parameterizing the system, two investigators (one from public health[6] and one from systems engineering[7]) collaborated, bringing their expertise

---

[6] Holly Schuh, MPH, PhD(c), author of this doctoral thesis
[7] Takeru Igusa, PhD, School of Engineering, Johns Hopkins University

together to construct the model and generate output. The base model was created using Matlab (MathWorks, 2016).

Using the multiple years of data for system readiness components (four years) and system coverage components (two years bookending the four *readiness* years), equations were used to calculate the parameters for the model (single arrows). Based on the stock and flow diagram (Figure 27), the equation for $SBA_{year2-1}$ takes into account ANC_{year1}, $Demand_{year1}$, and $HWcap_{year1}$. This equation for SBA is as follows:

$$SBA_{year2-1} = \beta_{SBA,0} + \beta_{SBA,1}*SBA_{year1} + \beta_{SBA,2}*ANC_{year1} + \beta_{SBA,3}*Demand + \beta_{SBA,4}*Health\ Workers_{year1}$$

The hypothesized relationship is that the change of SBA from year 1 to year 2 depends on SBA at year 1 as well as ANC and Health Workers at year 1. The Demand component is a constant (only one year of data was available). A full SD model is created by completing these equations for one time step.

The remaining equations for the full SD model that show the change from year 1 to year 2 are as follows:

$$ANC_{year2-1} = \beta_{ANC,0} + \beta_{ANC,1}*ANC_{year1} + \beta_{ANC,2}*Health\ Workers_{year1} + \beta_{SBA,3}*Demand$$

$$Health\ Workers_{year2-1} = \beta_{HW,0} + \beta_{HW,1}*Health\ Workers_{year1} + \beta_{HW,2}*Cold\ Chain_{year1} + \beta_{HW,3}*Basic\ Lab + \beta_{HW,4}*ANC + \beta_{HW,5}*SBA + \beta_{HW,6}*PENTA3$$

$$Basic\ Lab_{year2-1} = \beta_{BL,0} + \beta_{BL,1}*Basic\ Lab_{year1} + \beta_{BL,2}*Health\ Workers_{year1}$$

$$Vaccines_{year2-1} = \beta_{V,0} + \beta_{V,1}*Vaccines_{year1} + \beta_{V,2}*Cold\ Chain_{year1} + \beta_{V,3}*Health\ Workers + \beta_{V,4}*PENTA3$$

$$Cold\ Chain_{year2-1} = \beta_{CC,0} + \beta_{CC,1}*Cold\ Chain_{year1} + \beta_{CC,2}*Health\ Workers_{year1} + \beta_{CC,3}*Health\ Workers_{year1} + \beta_{CC,4}*Vaccines_{year1}$$

$$PENTA3_{year2-1} = \beta_{P,0} + \beta_{P,1}*Vaccines_{year1} + \beta_{P,2}*Health\ Workers + \beta_{V,3}*Demand$$

Regression lines were fitted for data with multiple years using least squares estimation. The SD model was fitted with these regression lines. The standard errors of the model coefficients and associated p-values were determined by using the statistical bootstrap procedure (Efron & Tibshirani, 1998).

5.5 Results

5.5.1 Base model

The base model is developed according to the stock and flow diagram (shown in Figure 27), and Table 16 presents a complete list of component relationships according to regression models for system stocks. Of the results for proposed coverage outcomes (Table 15), the primary component affecting ANC was Health Workers; for every one unit increase in Health Workers, ANC is expected to decrease 1.648 percentage points per year. This estimate was marginally statistically significant ($p=0.07$). The main components significantly affecting SBA were ANC and Demand. For every percentage-point increase in ANC, SBA is expected to decrease 0.105 percentage points each year ($p<0.0001$). And for every unit increase in Demand, SBA is expected to improve by 0.52 percentage points each year ($p<0.0001$). There were no statistically significant system readiness components for PENTA3; however, the coefficient for the constant indicated that if all other system components are held constant, PENTA3 is expected to improve 1.769 percentage-points in a year.

Loop B1 represents the flow of vaccine stock capacity, exchanged for vaccinated children at the point of service delivery. These are provincial-level measures of the average vaccine stock capacity score across health facilities as well as the provincial-level measures of pentavalent coverage, so it is a macro-level representation of the flow of vaccine stock scores. Here vaccine stocks affect the inflow to PENTA3 and in return, PENTA3 affects the outflow from vaccine stocks. The effect on PENTA3 (one percentage-point increase in Vaccine produces a 0.063 percentage-point change in PENTA3 each year, p=0.76) and the effect on Vaccines (one percentage-point increase in PENTA3 caused a change of -0.006 percentage-points in Vaccines, p=0.22) were both not statistically significant. All statistically significant (p<0.05) and marginally statistically significant (p<0.10) predictors are in Table 17.

Loop B2 represents the flow of provincial-level Health Workers capacity (treated as a stock) during vaccination services. These are provincial-level measures of the average Health Workers score as well as PENTA3. The exchange is again macro-level where the stock Health Workers contributes to the inflow of PENTA3, and PENTA3 depletes Health Workers. This dynamic between Health Workers and service coverage is repeated for SBA and ANC in loops B3 and B4, respectively. For loop B2, Health Workers affect the inflow to PENTA3 and Health Workers affect the outflow from Health Workers. Neither of these beta coefficients were statistically significant (p=0.42 and 0.78, respectively). In loop B3, Health Workers affects the inflow to SBA and SBA affects the outflow of Health Worker. One unit increase in the Health Workers (PCA) score is expected to decrease SBA by 0.025 percentage-points, though the coefficient is not statistically significant (p=0.94). This indicates that if the Health Workers score, based on provincial-average health worker counts at facilities, would increase, SBA would decrease. Also not found to be statistically significant, a one-percentage point increase in SBA would produce an increase of 0.001 units in Health Worker each year (p=0.90). In loop B4, the anticipated impact of Health Workers on ANC was statistically significant (-1.648 percentage-points per year, p=0.07), as mentioned above. However, the expected effect of ANC on Health Workers is not significant (-0.004 units per year, $p=0.56$).

Loop B5 depicts the exchange between Cold Chain and Vaccines, which describes the importance of transport, storage, and management capacity for maintaining enough vaccines at health facilities. Neither Vaccines nor Cold Chain have a statistically significant effect on the other (Vaccines on Cold Chain, $p=0.27$; Cold Chain on Vaccines, $p=0.82$). R1 (Health workers and Cold Chain) and R2 (Health Workers and Basic Lab) are the last two labelled loops of the system; none of the coefficients of the flows are statistically significant. There are other unlabeled reinforcing feedback loops in the system represented in the regression models, and they represent the effect of a past stock value affecting its own subsequent stock value (i.e. Health Workers$_{\text{Time2-1}}$ affected by Health Workers$_{\text{Time1}}$). Each loop has statistically significant coefficients. If Vaccines increases by one percentage-point during one year, Vaccines is expected to decrease in the next year by 0.19 percentage points ($p<0.0001$). If Cold Chain or Basic Lab or Health Workers increases by one percentage-point during one year, it is expected to decrease by 0.211 ($p<0.0001$), 0.198 ($p<0.0001$), and 0.203 ($p<0.0001$) percentage points (units for Health Workers) each year, respectively.

For each of the regression models, coefficients of the constants for ANC, SBA, and PENTA3 as well as Health Workers and Cold Chain are statistically significant, which occurs if all other beta coefficients are zero (components are held constant). If all components for the ANC regression model are held constant, then ANC would increase by 7.64 percentage points each year ($p<0.0001$). If all components for the SBA and PENTA3 regression models are held constant, then they would increase by 1.514

($p<0.0001$) and 1.769 ($p=0.04$) percentage points each year, respectively. If all components are held constant in the Cold Chain or Health Workers regression models, then they would decrease by 0.381-percentage points ($p=<0.0001$) and 0.334 units ($p<0.0001$) each year, respectively.

5.6 Discussion

Based on the design of the systems model, Health Workers connects with each of the other six stocks. It had a significant effect on only two of those components (ANC and itself). The relationship was the opposite from what was expected (increase in Health Workers negatively impacting ANC). Health Workers was measured by creating scores based on counts of different types of health workers. It may be that capacity for ANC requires more than just having the right health providers present. Moreover, counts were included if additional health worker counts whose work is not related to ANC (e.g. vaccinators). Having maternal health service-specific providers as a part of the score may change the marginally statistically significant outcome.

Two areas of the system were difficult to model: the connections between Vaccines and PENTA3 as well as the relationship between ANC and SBA. ANC on SBA is negative, and typically this would be positive because we are trying to confirm the structure of the system. Connections between ANC and SBA has been well-documented in literature. According to Akseer et al. (2016), SBA in Afghanistan has gradually improved since 2003-04 (14.3%, 13.7-15.0) until 2011-12 (46.1%, 44.8-47.4%), and ANC has had similar improvements (16.1% to 52.9%, respectively) (Akseer et al., 2016). Typically, receipt of antenatal care services has been linked with future deliveries with skilled birth attendants, which was the case for a study in Afghanistan as well (Tappis et al., 2016). Findings from our study suggest differently; this may be linked to different patterns in health seeking such as the behavior of bypassing primary health care facilities for maternal health services only to receive care at a comparable facility or higher level clinic or district hospital (Tappis et al., 2016). Our data only include facilities that deliver the BPHS and provide information on system readiness for delivering immunization services. There may be additional system readiness components that would affect the system behavior regarding maternal health services.

The variable for Vaccines was found to be a persistent, statistically significant predictor of PENTA3 in Chapter 3. In this study, Vaccines and PENTA3 affect one another in a predictable manner (Vaccines improves PENTA3 and PENTA3 depletes Vaccines), except that coefficients were not statistically significant. Moreover, no systems readiness components were found to change Vaccines to a statistically significant extent except for Vaccines itself. There may be a missing component, which, if identified, might help to define how Vaccines and PENTA3 coverage interact. Also, Demand was found to be statistically significant only for SBA and not PENTA3 or ANC. The Demand measure was intended to measure demand factors for vaccination, but it may be that the current construct is a better representation of demand factors for maternal health services. Despite having no statistically significant predictors for PENTA3, our model appears to produce a trend similar to historical information. Akseer and colleagues (2016) compare WHO/UNICEF estimates and trends in maternal and child health care services. WHO/UNICEF estimates tend to be higher than (but not statistically different from) those reported from independent surveys (Tao et al., 2013), but the general trend of gradual improvements in vaccination coverage remains the same. PENTA3 vaccination coverage improved gradually over time, approximating a couple of percentage points each year (Akseer et al., 2016).

Each of the system readiness stock components (e.g. Vaccines, Cold Chain, etc.) has a reinforcing loop back to its own inflow. The anticipated year-to-year effects of each of the system readiness factors on itself were mostly negative, meaning that the stock is depleting itself year-to-year while holding all other components constant. This is in the opposite direction from what was expected and could indicate that system readiness for immunization services today is not a stable indication of tomorrow's readiness. This pattern could also be due to the many reinforcing feedback loops that cause the system to accumulate the reinforcing behavior over time, leaving no places for the stocks to flow except back through the inflows. This may have to do with the SD model in that there are more components contributing to inflows and few outflows (18 versus 5, respectively).

Balancing loops were created in the stock and flow diagram (Figure 27) to counter the likely over-powering effect of reinforcing loops in the reduced, simplified full immunization system (Figure 26). For example, the overall effect of *demand* (through *health worker workload)* on *health worker capacity* is depleting if *demand* increases. No variable exists for health worker workload, and *demand* was modelled as an auxiliary variable because of the limited time points of *demand* data. *Demand's* effect on health worker capacity was instead modelled as each of the health service outcome variables (i.e. SBA, ANC, and PENTA3) affecting the outflow of Health Workers. Regardless of finding ways to balance the system by thinking of other ways to represent the feedback loops in Figure 26, reinforcing loops dominate the system in Figure 26 and 27 causing inflows to become negative there are no other paths for stocks to outflow.

5.6.1 Limitations

Secondary data were used to populate the models. Multiple-year outcome data and data for Demand were unavailable. At most, two time points bookending the NHSPA years were used in this study. This limits the information for the middle years, and we assumed that measures followed a linear trend between 2007-08 and 2012-13.

Investigators faced a challenge in identifying variables to represent predictors and outcomes of models. Because demand is known as an important factor in national immunization program progress yet has been difficult to define, many variables could be used to represent it. On the other hand, developed measures could also miss an important part of demand, causing information bias and an ill-represented Demand component in the model.

Because aggregation of causal connections (e.g. "+" through "-" pathway resulted in one connection ("-") omitting the middle variable in Paper 2) was necessary for examining changes in provincial-level health services coverage estimates, variable selection was limited and causal pathways represented macro-level feedback in the system. Similar to ecological studies, an assumption of homogeneity limits our understanding of system behavior that may occur in multiple feedback loops that comprise the larger feedback loops represented in the SD model.

SD models operate based on the assumption that one small change can compound over time causing significant and even unanticipated changes to system behavior. The SD model in this study represents our best attempt to represent the dynamic effects of immunization service readiness on immunization and non-immunization performance, given the available data while integrating the statistical information of step 1 and the expertise encapsulated in the CLDs in step 2.

5.7 Conclusion

As health systems research continues to grow, SD modeling may contribute to future confirmatory studies of health subsystems and systems structure and behavior using already existing data. This study confirmed the majority of aspects of the structure of the immunization subsystem, which was first conceptually mapped in Chapter 4. The base SD model can produce third-dose of Pentavalent and antenatal care coverage trends similar to those found in literature. Model output suggests that the connections between health worker capacity and ANC coverage, ANC and SBA coverage as well as the role of actors (health workers and people represented by Demand) are important to immunization and maternal health service outcomes. More investigation is needed to unpack the interconnectedness of actors and their behavior in the system, and how this interconnectedness translates into system behavior. This study is an example of an engineering and public health partnership, and the SD model will be useful for future exploratory modeling to test different policy options for immunization in Afghanistan and other developing and/or conflict-affected countries.

5.8 Recommendations

For a more complete understanding of the immunization system, it is suggested that each of the subsystems be explored at a lower level of analysis than the provincial-level analysis presented in this paper. This would entail making use of the CLDs presented in Chapter 4 that may be modeled separately in confirmatory modeling exercises. Such an exercise would require other sources of data including those from primary data collection and/or scale development for latent variables that have been difficult to define and measure (e.g. trust). Context-specific data collection should employ partnerships with local experts across different disciplines such as anthropology or sociology as well as experts in development, management, and consumer behavior. The SD model represented in this paper is the beginning of not only exploratory modeling exercises at a macro-policy level but it could be the beginning for confirmatory subsystem analyses at regional and local policy levels. More stable environments might be better suited for carrying out the suggested exercises, but systems modeling of contexts such as Afghanistan (with security- and environment-specific information) may benefit our understanding of system structure and adaptation when stability is unreliable.

5.9 Chapter 5 Tables and Figures

Table 15. Model components, stock and flow diagram labels, and component descriptions

Model information component	Model Label	Description	Time points
System readiness stocks:			
Provincial average: vaccine stock mean index scores	Vaccines	Vaccine stock index scores by rating items (0 or 1) related to vaccine stocks (present, missing, expired) at health facilities	2008-2012, 4 years/time points
Provincial average: cold chain capacity mean index scores	Cold Chain	Cold chain index scores by rating items (0 or 1) related to vaccine transport, management and storage at health facilities	2008-2012, 4 years/time points
PCA* score: provincial average health worker counts	Health Workers	PCA* score of the following components: provincial average health worker counts (vaccinators, physicians practicing obstetrics and gynecology, nurses, midlevel clinicians, and general physicians)	2008-2012, 4 years/time points
Provincial average: basic laboratory capacity index scores for Vaccine Preventable Diseases	Basic Lab	Basic laboratory index scores by rating items (0 or 1) related to laboratory equipment and test availability at health facilities	2008-2012, 4 years/time points
Outcomes of interest:			
Provincial average: Pentavalent3 coverage	PENTA3	Percent of eligible 12-23-month-old children who have received their third dose of pentavalent vaccine	2007-08 & 2012-13, 2 years/time points
Provincial average: ANC coverage	ANC	Percent of ever-married women age 12-49 years who have been pregnant with a live birth outcome in the past two years who have received at least one antenatal care visit	2007-08 & 2012-13, 2 years/time points
Provincial average: SBA coverage	SBA	Percent of ever-married women age 12-49 years who have been pregnant with a live birth outcome in the past two year who delivered with a skilled birth attendant present	2007-08 & 2012-13, 2 years/time points
System readiness auxiliary (constant):			
PCA* score: combination of provincial average percentages/coverages of seven demand-related components	Demand	PCA* score of the following components: percent of poorest, middle, and richest households, percent of mothers who have ever had a formal education, percent of households that live within two hours from the nearest health facility, percent of currently married women age 12-49 years who currently use a form of modern contraceptives (includes female sterilization, intra-uterine device, contraceptive pill, contraceptive injection, and condom), and percent of ever-breastfed children born in the two years prior to the survey (survived or dead) to ever-married women age 12-49 years	2012-13, 1 year/time points

* PCA: principal component analysis

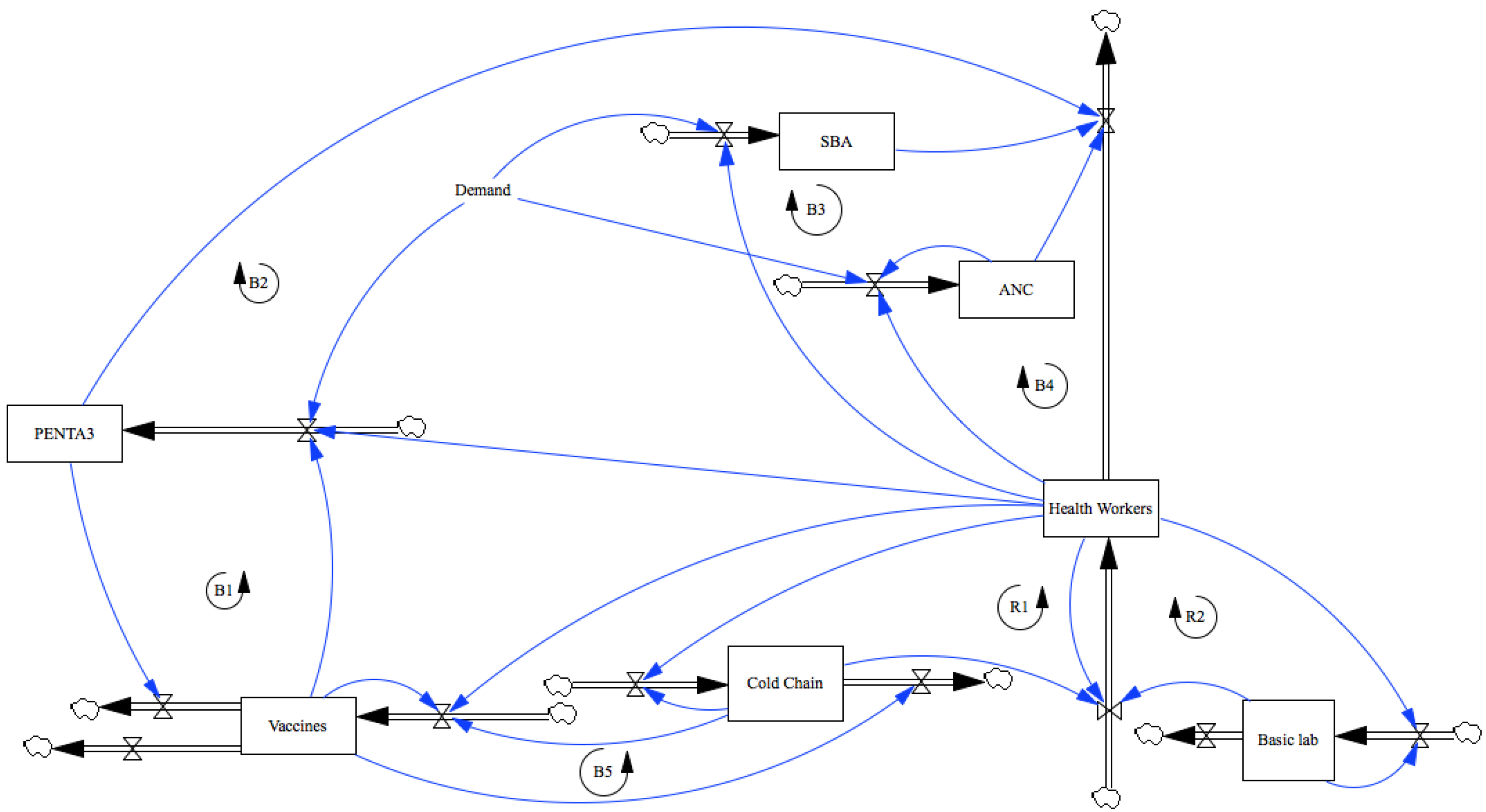


Figure 27. Full system dynamics Afghanistan immunization system - maternal health service tradeoffs model

Table 16. List of component relationships according to regression models for system stocks

	Flow	Coefficient for the following stock. (Blank = constant negative flow)
ANC	dA	*
	dA	ANC
	dA	Demand
	dA	Health Workers*
SBA	dS	*
	dS	ANC*
	dS	Demand*
	dS	Health Workers
PENTA3	dP	*
	dP	Demand
	dP	Health Workers
	dP	Vaccines
Health Workers	dH	*
	dH	Health Workers*
	dH	ANC
	dH	SBA
	dH	Basic Lab
	dH	Cold Chain
	dH	PENTA3
Basic Lab	dL	**
	dL	Basic Lab*
	dL	Health Workers
Cold Chain	dC	*
	dC	Cold Chain*
	dC	Health Workers
	dC	Vaccines
Vaccines	dV	
	dV	Vaccines*
	dV	Health Workers
	dV	PENTA3
	dV	Cold Chain

* $p<0.05$; ** $p<0.10$

Table 17. Statistically significant regression model parameter beta coefficients (p<0.10)

	Flow	Stock variable (Blank = constant negative flow)	Equation	Coefficient	Standard error	p-value
			Coverage outcomes			
ANC	dA		$ANC_{year2-1} = \beta_{ANC,0}$	7.64	0.654	0.00
	dA	Health Workers	$ANC_{year2-1} = \beta_{ANC,0} + \beta_{ANC,2}$*Health $Workers_{year1}$	-1.648	0.925	0.07*
SBA	dS		$SBA_{year2-1} = \beta_{SBA,0}$	1.514	0.275	0.00
	dS	ANC	$SBA_{year2-1} = \beta_{SBA,0} + \beta_{SBA,2}$*$ANC_{year1}$	-0.105	0.024	0.00
	dS	Demand	$SBA_{year2-1} = \beta_{SBA,0} + \beta_{SBA,3}$*Demand	0.52	0.174	0.00
PENTA3	dP		$PENTA3_{year2-1} = \beta_{P,0}$	1.769	0.864	0.04
			System readiness components			
Health Workers	dH		Health $Workers_{year2-1} = \beta_{HW,0}$	0.334	0.018	0.00
	dH	Health Workers	Health $Workers_{year2-1} = \beta_{HW,0} + \beta_{HW,1}$*Health $Workers_{year1}$	-0.203	0.048	0.00
Basic Lab	dL		Basic $Lab_{year2-1} = \beta_{BL,0}$	0.647	0.352	0.07*
	dL	Basic Lab	Basic $Lab_{year2-1} = \beta_{BL,0} + \beta_{BL,1}$*Basic Lab_{year1}	-0.198	0.027	0.00
Cold Chain	dC		Cold $Chain_{year2-1} = \beta_{CC,0}$	-0.381	0.13	0.00
	dC	Cold Chain	Cold $Chain_{year2-1} = \beta_{CC,0} + \beta_{CC,1}$*Cold $Chain_{year1}$	-0.211	0.051	0.00
Vaccines	dV	Vaccines	$Vaccines_{year2-1} = \beta_{V,0} + \beta_{V,1}$*$Vaccines_{year1}$	-0.19	0.018	0.00

* marginally, statistically significant (p<0.10)

Intended to be blank.

Chapter 6. Summary of findings and recommendations

6.1 Summary of findings

From Paper 1 (Study 1, Chapter 3), two systems readiness exposures were associated with current provincial immunization coverage (vaccine stock readiness and vaccine-related laboratory capacity). In this ecological study, we were limited to describing non-causal associations between covariates and immunization coverage. We tried to make use of multiple years of facility-based data (from the NHSPAs as described in Chapter 2) to provide some time-related context to the measures. The dependent variable is measured during the last year of readiness measures (2012), which allows us to know that the outcome measure occurs after the majority of readiness covariate measures. Temporality is also difficult to establish because the models are describing past ecological readiness in relationship with a more "current" ecological measure of service coverage.

Also in Study 1 (Chapter 3), cold chain functionality was not statistically significantly associated with current immunization coverage. This may have been because facility and equipment characteristics that show capacity to maintain, store, and transport vaccines to communities are less informative than measures that explain capacity to transport vaccines to health facilities. Instead, improving vaccine stock scores, which represent the result or outcome of a functioning cold chain systems, were significantly associated with immunization coverage. However, we know that if health facilities have poor ability to maintain and store vaccines or to transport them to community settings for outreach, vaccination service delivery would be affected.

Demand-side factors of wealth status as well as factors that indicate patterns in mothers' health behaviors (i.e. second dose of tetanus toxoid and exclusive breastfeeding practices) were also statistically significant in most of the wealth-specific models in Paper 1. Mother's educational status and traveling distance were two covariates that were only marginally statistically significant in models controlling for distributions of middle-income households (every ten point increase is associated with a 4.29 (95% CI: 1.23, 7.34) and 1.61 (95% CI: -0.04, 3.25) percentage-point increase in immunization coverage, respectively). While controlling for poorest households, the association between mothers' health practices like exclusive breastfeeding and tetanus toxoid vaccination coverage were slightly larger than when controlling for distributions of middle- and richest-income households. Wealth status was a significant predictor of immunization coverage except for richest households. If the middle-income household group increases, immunization coverage also will increase, which is the opposite associated effect when increasing the proportion of poorest households.

Demand-side factors come from the same data that were used to calculate the dependent variable measuring immunization coverage (i.e. 2012-13 household data). Though associations are found to be statistically significant, temporality and causality become difficult to determine especially given the ecological study design. Limitations of the study design can be considered in light of the evidence found in literature on factors associated with immunization coverage (Favin et al., 2012). At most, exposures in this study as well as factors found in literature may be considered factors associated with immunization coverage, but causal mechanisms have been less examined. This represents a gap in understanding health seeking behaviors, especially in contexts where system structure is vulnerable to exogenous shocks.

In Study 2 (Paper 2, Chapter 4), four subsystems of the immunization system (i.e. health facilities capacities like functioning cold chain and vaccine stock movement around a routine immunization system, basic laboratory capacity at health facilities with laboratories, health worker capacity at health facilities, and demand-side factors) showed the linkage between actors and other system components. Though first versions of CLDs kept health worker characteristics in the health worker subsystem, expert feedback was directed at the "human" element of immunization programs and how actor behavior is never separate from functions of the different parts of the system. In SS1, experts noted that vaccine management and logisticians' skills should be a part of the diagram. In SS2, experts emphasized the link between laboratory/surveillance capacity and local authority awareness and involvement in immunization. SS3 would have continued to grow if spillover of human resource elements into other subsystems had not happened. Experts connected the most with SS3 because of the combined focus on human resources as well as communities and individuals by inclusion of *demand* for vaccination.

The demand loop in SS3 and SS4 (Figures 16 and 20, Chapter 4) contained components that represent the overlap of demand and system readiness (or supply) in immunization systems. Despite the inclusion of different aspects of vaccine demand, we have limited data to create a demand construct for the model. Definitions and measurement of vaccine demand have also recently been a point of discussion among the global immunization community. The roles of laboratory and surveillance capacity in immunization outcomes were depicted broadly by creating pathways through local authorities, political and financial commitment to surveillance, and subsequent support of health worker knowledge and skills in the system.

For most of the experts who reviewed the CLDs, it was their first encounter with CLDs. CLDs are designed with the intention of fostering discussion; their complex, causally-explicit characteristics incite input from informed individuals because of the wealth of components and relationships represented. Though we were not able to develop the CLDs as a collective group over a series of meetings, the iterative process of creating CLDs was mimicked through the expert review process. It is likely that more context-specific discussions may have been fostered by in-person, group discussions. The CLDs offered explicitness on causality where Study 1 (Paper 1, Chapter 3) findings were limited to non-causal associations. This same explicitness is carried forward in Study 3 (Paper 3, Chapter 5) using SD modeling.

When reducing SS1-4 into one full immunization system CLD in Study 2 (Figure 26, Chapter 4), reinforcing loops dominated the routine immunization system. Balancing loops combined and reinforcing loops resulted to link system components for which we had empirical data. Creating this macro-level version of the CLDs was necessary for moving to the next step of SD modeling. Decisions on which components to include were limited based on data availability, but the integrity of the structure was maintained as best as possible by adhering to principles of CLDs (i.e. multiplication of component relationships to arrive at broad relationships or for determining if a feedback loop is balancing or reinforcing as explained in Section 4.3.2 of Chapter 4). It is important to recognize that CLDs are not intended to be perfect, and similar to SD models, their value is related to the backgrounds of expertise represented in their creators. We intended for the CLDs represented in this thesis to guide discussions and model development based on system structure and complexity (i.e. interconnectedness of the system components).

Through the system confirmatory exercise in Study 3 (Paper 3, Chapter 5), the SD model showed that when considering system structure, coverage estimates for the stocks of PENTA3 (1-2 percentage point improvements year-to-year) and ANC (5-7 percentage-point improvements year-to-year) do show behavior similar to historical trends of the same measures (Akseer et al., 2016). Both the auxiliary variable of demand-side factors and the stock of health worker capacity were found to be significant influencers of year-to-year changes in maternal health service coverage stocks (Table 17, Chapter 5). System behavior may be predominantly driven by the reinforcing feedback loops that the structure was originally based on, especially among the system readiness components. Feedback loops were adapted because of the need to balance the system to facilitate achieving equilibrium. Year-to-year changes in system readiness stocks exhibited declines in performance, which may be a result of the original reinforcing feedback loop structure, data quality, or form of the variables. These trends may also be informative about system readiness and its resiliency across year time steps, which may be too large to indicate more accurate tolerance and resiliency of system readiness over time. In the context of Afghanistan where, for example, vaccine stocks may be plentiful for one quarter and dwindling in the next due to various exogenous threats to the logistics/cold chain system.

6.2 Recommendations

The thesis research presented in this dissertation represents formative research efforts to examine subsystem-system tradeoffs (i.e. behavior) in the Afghanistan health system. This body of research work is intended to be a basic example of examination of system structure and system behavior using methods that can account for complexity and feedback. Recommendations are, therefore, building on this work as well as the premise of contributing to the field methodologically. They are presented according to relevancy: 1) to this research and the Afghan context, and 2) to the methods and field of health systems research.

Relevant to this thesis research and the context of Afghanistan

Now that a macro-level SD model has been created, a closer look at each of the subsystems using SD modeling would be useful for understanding mechanisms of system behavior. Confirmatory exercises for subsystems would require primary data collection and further development of the CLDs presented in Study 2 (Paper 2, Chapter 4). The SD model presented in this thesis (Study 3, Chapter 5) could be the start of regional and local policy level exploratory exercises in the Afghanistan immunization system to test candidate interventions for their effects on immunization and non-immunization coverage outcomes.

Given the nature of the Afghan context where it is likely that many exogenous threats affect health service delivery, it may be worthwhile to develop measures that can capture these phenomenon or factors in order to gain a better understanding about how the system adapts (or does not adapt). There was no inclusion of security-related information in the quantitative models due to the poor quality of security-related data that exists for Afghanistan. It may be useful to move to a “more stable” environment to create measures for security (recognizing that all health systems are complex and adaptive) to determine how to computationally represent the instability of the health system using methodologies such as SD modeling.

Given current immunization-focused literature and the emphasis in Studies 1-3 of this dissertation (Chapters 3-5), the dynamics of logistics systems, their architecture, and adequate supply of vaccines could be explored in more detail (e.g. Figure 8, Study 2). At the point of vaccination service delivery (the most proximal situation to "vaccinated status" for children), the necessary vaccines and a health worker to provide the vaccination must both be present. Instead of thinking of logistics systems as a series of linearly-related components and processes, qualitative and quantitative systems models can help to measure unintended effects of changes to the logistics system architecture.

Given the importance of actors (in this thesis research, health workers and consumers of vaccination and maternal health services) in the immunization system of Afghanistan, future research and practice efforts should focus on their interaction with health service delivery systems. Regarding health workers, more data specific to the function of health workers, their interconnections, and their interaction with the health system are required for better understanding the role that health workers play in the Afghanistan immunization system. Our data were limited to health worker counts and refresher training information, but health worker capacity likely entails more than these inventory-oriented measures. Regarding demand-side actors, mothers in Afghanistan are likely faced with many barriers to accessing care not only for themselves but also for their children. Their health seeking behaviors (and decision-making) could be explored in the Afghan context and, moreover, how the health system fosters their health behaviors.

Relevant to the methods and the field of Health Systems Research

In terms of practice and research, it is recommended that decision-makers and stakeholders be involved from the beginning of the processes described throughout the methodologies of this dissertation. Particularly when considering less common methods in public health research like CLD development and SD modeling, stakeholder involvement from research/policy question formation to base model development would facilitate acceptability of the models and any unexpected effects that the system produces when testing candidate interventions.

The role of laboratory and surveillance subsystems in immunization systems is not well understood, but findings from our studies (as well as found in literature) provide evidence of their importance in health service coverage. Often both laboratory and surveillance capacities are treated as secondary or supplementary to the priority of having vaccines in stock at health facilities and health workers to vaccinate children. It may be that laboratories at facilities and/or effective surveillance systems have more of an impact on country immunization programs than we think or can at this point understand. Specific to Afghanistan, we found that basic laboratory capacity is significantly associated with immunization coverage (Study 1, Chapter 3), but more data and conceptual work is needed to identify the pathways through which laboratories and surveillance positively and negatively impact immunization and other areas of the health system (e.g. Figure 9 in Study 2, Chapter 4).

Regarding another group of actors in the health system, a better understanding of demand for vaccination services should be examined for its role in routine immunization systems. Because demand was highlighted as a key component of system readiness (and it is emphasized in immunization policy as a critical part of immunization program readiness), exploration of demand and development of adaptable measures would be useful for managers of health programs and program evaluators. This likely requires attention to more than just consumers of immunization and other health services but also those who are a part of or contribute to the structure that fosters health seeking behaviors. Approaches should account for the complexity of factors and pathways that influence health seeking behaviors and examination of the points of intersection between system and demand.

CLDs are becoming more published in both the public health and health systems research literature. They can take different forms of examining historical development of systems, comprehensively representing cross-sectional views of the system, or exploring hypothetical scenarios that exhibit changes in behavior across cross-sectional views of the system (Ozawa et al., 2016; A. S. Rwashana et al., 2009; Varghese et al., 2014). CLDs could be useful not only for addressing research and policy, but they could also be used as teaching tools for raising awareness among health program managers about the system (i.e. system) architecture within which they operate on a day-to-day basis.

Health systems and subsystems are examples of the many possibilities of objects of study in public health research, and questions that help us understand their behavior likely require methods that can account for complexity. The systems sciences offer a wealth of expertise and methodologies that are relevant and useful in health systems research. Different thought paradigms could be represented by these two phrases: if one is “a researcher who studies health systems” versus “a systems researcher whose main focus is the behavior of (health) systems”. One treats health systems as an area of expertise with assumed technical expertise (grounded in public health research). The other treats health systems as objects of study that are observed from a different technical expertise background (grounded in systems sciences). In order to advocate for the importance of the growing field of health systems research, the meaning conveyed by the latter phrase should guide the growth of the field. That is, health systems research should not become another independent, siloed area of public health research. Rather, the systems knowledge, perspective, and approach that drive health systems research should allow health *systems* research to be an overarching theme that transcends public health specialties (similar to the principles of epidemiology and biostatistics that undergird all aspects of public health research). Such a culture and cause would shift priorities and funding in multiple areas of research, not just health systems research.

Intended to be blank.

References

Acerra, J. R., Iskyan, K., & Qureshi, Z. A. (2009). Rebuilding the health care system in Afghanistan : an overview of primary care and emergency services, 77–82. https://doi.org/10.1007/s12245-009-0106-y

Adam, T., & de Savigny, D. (2012). Systems thinking for strengthening health systems in LMICs: need for a paradigm shift. *Health Policy and Planning*, *27*(suppl 4), iv1-iv3. https://doi.org/10.1093/heapol/czs084

Adam, T., Hsu, J., De Savigny, D., Lavis, J. N., Rottingen, J. A., & Bennett, S. (2012). Evaluating health systems strengthening interventions in low-income and middle-income countries: Are we asking the right questions? *Health Policy and Planning*, *27*(SUPPL. 4). https://doi.org/10.1093/heapol/czs086

Afghan Ministry of Public Health, Johns Hopkins Bloomberg School of Public Health, & Indian Institute of Health Management Research. (2012). *Afghanistan Health Survey (AHS) 2012*. Kabul.

Akseer, N., Salehi, A. S., Hossain, S. M. M., Mashal, M. T., Rasooly, M. H., Bhatti, Z., … Bhutta, Z. A. (2016). Achieving maternal and child health gains in Afghanistan: A Countdown to 2015 country case study. *The Lancet Global Health*, *4*(6), e395–e413. https://doi.org/10.1016/S2214-109X(16)30002-X

Arur, A., Peters, D., Hansen, P., Mashkoor, M. A., Steinhardt, L. C., & Burnham, G. (2010). Contracting for health and curative care use in Afghanistan between 2004 and 2005. *Health Policy and Planning*, *25*(2), 135–144. https://doi.org/10.1093/heapol/czp045

Ateudjieu, J., Kenfack, B., Nkontchou, B. W., & Demanou, M. (2013). Program on immunization and cold chain monitoring : the status in eight health districts in Cameroon.

Atun, R. (2012). Health systems, systems thinking and innovation. *Health Policy and Planning*, *27*(suppl 4), iv4-iv8. https://doi.org/10.1093/heapol/czs088

Atun, R., Weil, D. E., Eang, M. T., & Mwakyusa, D. (2010). Health-system strengthening and tuberculosis control. *The Lancet*, *375*(9732), 2169–2178. https://doi.org/10.1016/S0140-6736(10)60493-X

Babalola, S., & Fatusi, A. (2009). Determinants of use of maternal health services in Nigeria--looking beyond individual and household factors. *BMC Pregnancy and Childbirth*, *9*, 43. https://doi.org/10.1186/1471-2393-9-43

Béhague, D. P., & Storeng, K. T. (2008). Collapsing the vertical-horizontal divide: An ethnographic study of evidence-based policymaking in maternal health. *American Journal of Public Health*, *98*(4), 644–649. https://doi.org/10.2105/AJPH.2007.123117

Bhushan, I., Keller, S., Schwartz, B., Bank, A. D., & Economics, A. D. B. (2002). Achieving the twin objectives of efficiency and equity: contracting health services in Cambodia. *Asian Development Bank*, (6), 13. Retrieved from http://www.asiandevbank.org/Documents/EDRC/Policy_Briefs/PB006.pdf

Biesma, R. G., Brugha, R., Harmer, A., Walsh, A., Spicer, N., & Walt, G. (2009). The effects of global health initiatives on country health systems: A review of the evidence from HIV/AIDS control. *Health Policy and Planning*, *24*(4), 239–252. https://doi.org/10.1093/heapol/czp025

Bishai, D., Suzuki, E., Mcquestion, M., Chakraborty, J., & Koenig, M. (2002). The role of public health programmes in reducing socioeconomic inequities in childhood immunization coverage. *Health Policy and Planning*, *17*(4), 412–419.

Boerma, T., Abou-Zahr, C., Bos, E., Hansen, P., Addai, E., & Low-Beer, D. (2009). *Monitoring and evaluation of health systems strengthening: An operational framework*. Geneva. Retrieved from http://www.who.int/healthinfo/HSS_MandE_framework_Nov_2009.pdf

Bosch-Capblanch, X., Banerjee, K., & Burton, A. (2012). Unvaccinated children in years of increasing coverage: how many and who are they? Evidence from 96 low- and middle-income countries. *Tropical Medicine & International Health*, *17*(6), 697–710. https://doi.org/10.1111/j.1365-3156.2012.02989.x

Bryce, J., Victora, C. G., & Black, R. E. (2013). The unfinished agenda in child survival. *The Lancet*, *382*(9897), 1049–1059. https://doi.org/10.1016/S0140-6736(13)61753-5

Burchett, H. E. D., Mounier-jack, S., Torres-rueda, S., Griffiths, U. K., Ongolo-zogo, P., Rulisa, S., … Mills, A. (2014). The impact of introducing new vaccines on the health system : Case studies from six low- and middle-income countries, *32*(48), 6505–6512. https://doi.org/10.1016/j.vaccine.2014.09.031

Butler, R., & MacDonald, N. E. (2015). Diagnosing the determinants of vaccine hesitancy in specific subgroups: The Guide to Tailoring Immunization Programmes (TIP). *Vaccine*, *33*, 4176–4179. https://doi.org/10.1016/j.vaccine.2015.04.038

Cappelen, A., Mæstad, O., & Tungodden, B. (2010). Demand for Childhood Vaccination – Insights from Behavioral Economics. *Forum for Development Studies*, *37*(3), 349–364. https://doi.org/10.1080/08039410.2010.507778

Cardol, M., Groenewegen, P. P., de Bakker, D. H., Spreeuwenberg, P., van Dijk, L., & van den Bosch, W. (2005). Shared help seeking behaviour within families: a retrospective cohort study. *BMJ (Clinical Research Ed.)*, *330*(7496), 882. https://doi.org/10.1136/bmj.38411.378229.E0

Cavana, R. Y., & Maani, K. E. (2000). *A Methodological Framework for Integrating Systems Thinking and System Dynamics*. Auckland.

Chan Soeung, S., Grundy, J., Duncan, R., Thor, R., & Bilous, J. B. (2013). From reaching every district to reaching every community: Analysis and response to the challenge of equity in immunization in Cambodia. *Health Policy and Planning*, *28*(5), 526–535. https://doi.org/10.1093/heapol/czs096

Chopra, M., Sharkey, A., Dalmiya, N., Anthony, D., & Binkin, N. (2012). Strategies to improve health coverage and narrow the equity gap in child survival, health, and nutrition. *The Lancet*, *380*(9850), 1331–1340. https://doi.org/10.1016/S0140-6736(12)61423-8

Claeson, M., & Waldman, R. J. (2000). The evolution of child health programmes in developing countries : from targeting diseases to targeting people. *Bulletin of the World Health Organization*, *78*(10).

Clements, C. J., Watkins, M., de Quadros, C., Biellik, R., Hadler, J., McFarland, D., … Dietz, V. (2011). Researching routine immunization-do we know what we don't know? *Vaccine*, *29*(47), 8477–8482. https://doi.org/10.1016/j.vaccine.2011.08.048

Closser, S., Rosenthal, A., Parris, T., Maes, K., Justice, J., Cox, K., … Neergheen, V. (2012). Methods for evaluating the impact of vertical programs on health systems: protocol for a study on the impact of the global polio eradication initiative on

strengthening routine immunization and primary health care. *BMC Public Health*, *12*(1), 728. https://doi.org/10.1186/1471-2458-12-728
Cohen, R. L., Li, Y., Giese, R., & Mancuso, J. D. (2013). An evaluation of the President's Emergency Plan for AIDS Relief effect on health systems strengthening in sub-Saharan Africa. *Journal of Acquired Immune Deficiency Syndromes (1999)*, *62*(4), 471–9. https://doi.org/10.1097/QAI.0b013e3182816a86
Das, J., & Das, S. (2003). Trust, learning, and vaccination: a case study of a North Indian village. *Social Science & Medicine*, *57*(1), 97–112. https://doi.org/10.1016/S0277-9536(02)00302-7
Deroche, C. B. (2015). *Diagnostics and Model Selection for Generalized Linear Models and Generalized Estimating Equations*. University of South Carolina. Retrieved from h5p://scholarcommons.sc.edu/etd/3059
Dieleman, J. L., Schneider, M. T., Haakenstad, A., Singh, L., Sadat, N., Birger, M., … Murray, C. J. L. (2016). Development assistance for health : past trends , associations , and the future of international fi nancial fl ows for health, *387*. https://doi.org/10.1016/S0140-6736(16)30168-4
Duclos, P., Okwo-Bele, J.-M., Gacic-Dobo, M., & Cherian, T. (2009). Global immunization: status, progress, challenges and future. *BMC International Health and Human Rights*, *9 Suppl 1*, S2. https://doi.org/10.1186/1472-698X-9-S1-S2
Edward, A., Dwivedi, V., Mustafa, L., Hansen, P. M., Peters, D. H., & Burnham, G. (2009). Trends in the quality of health care for children aged less than 5 years in Afghanistan, 2004-2006. *Bulletin of the World Health Organization*, *87*(12), 940–949. https://doi.org/10.2471/BLT.08.054858
Edward, A., Kumar, B., Kakar, F., Salehi, A. S., Burnham, G., & Peters, D. H. (2011). Configuring balanced scorecards for measuring health system performance: Evidence from 5 years' evaluation in Afghanistan. *PLoS Medicine*, *8*(7). https://doi.org/10.1371/journal.pmed.1001066
Efron, B., & Tibshirani, R. J. (1998). *An introduction to the bootstrap*. Washington, DC: Chapman & Hall / CRC Press LLC. https://doi.org/10.1007/978-1-4899-4541-9
Favin, M., Steinglass, R., Fields, R., Banerjee, K., & Sawhney, M. (2012). Why children are not vaccinated: A review of the grey literature. *International Health*, *4*(4), 229–238. https://doi.org/10.1016/j.inhe.2012.07.004
Forrester, J. W. (1971). Counterintuitive behavior of social systems. *Theory and Decision*, *2*, 109–140. https://doi.org/10.1016/0040-1625(76)90044-5
Forrester, J. W. (2009). *Learning through System Dynamics as Preparation for the 21st Century*. Cambridge. https://doi.org/10.1002/sdr.4260100211
Gaafar, T., Moshni, E., & Lievano, F. (2003). The challenge of achieving measles elimination in the eastern Mediterranean region by 2010. *The Journal of Infectious Diseases*, *187 Suppl*(Suppl 1), S164-71. https://doi.org/10.1086/368035
Gauri, V., & Khaleghian, P. (2002). Immunization in Developing Countries : Its Political and Organizational Determinants, *30*(January), 2109–2132.
Gilson, L., Hanson, K., Sheikh, K., Agyepong, I. A., & Ssengooba, F. (2011). Building the Field of Health Policy and Systems Research : Social Science Matters, *8*(8). https://doi.org/10.1371/jour-systems
Gilson, L., Palmer, N., & Schneider, H. (2005). Trust and health worker performance : exploring a conceptual framework using South African evidence, *61*, 1418–1429.

https://doi.org/10.1016/j.socscimed.2004.11.062
Global Polio Eradication Initiative, & World Health Organization. (2017). Polio: Global Eradication Initiative. Retrieved February 23, 2017, from http://polioeradication.org/
Goodhand, J., & Sedra, M. (2010). Who owns the peace? Aid, reconstruction, and peacebuilding in Afghanistan. *Disasters*, *34*(SUPPL. 1), 78–102. https://doi.org/10.1111/j.1467-7717.2009.01100.x
Greenwood-Lee, J., Hawe, P., Nettel-Aguirre, A., Shiell, A., & Marshall, D. A. (2016). Complex intervention modelling should capture the dynamics of adaptation. *BMC Medical Research Methodology*, *16*(1), 1–7. https://doi.org/10.1186/s12874-016-0149-8
Griffiths, U. K., Mounier-Jack, S., Oliveira-Cruz, V., Balabanova, D., Hanvoravongchai, P., & Ongolo, P. (2011). How can measles eradication strengthen health care systems? *Journal of Infectious Diseases*, *204*(SUPPL. 1), 0–3. https://doi.org/10.1093/infdis/jir090
Haddad, S., Bicaba, A., Feletto, M., Taminy, E., Kabore, M., Ouedraogo, B., … Fournier, P. (2009). System-level determinants of immunization coverage disparities among health districts in Burkina Faso: a multiple case study. *BMC Int Health Hum Rights*, *9 Suppl 1*, S15. https://doi.org/10.1186/1472-698x-9-s1-s15
Hafner, T., & Shiffman, J. (2013). The emergence of global attention to health systems strengthening. *Health Policy and Planning*, *28*(1), 41–50. https://doi.org/10.1093/heapol/czs023
Hansen, P. M., Peters, D. H., Niayesh, H., Singh, L. P., Dwivedi, V., & Burnham, G. (2008). Measuring and managing progress in the establishment of basic health services: the Afghanistan Health Sector Balanced Scorecard. *International Journal of Health Planning and Management*, *23*, 107–117. https://doi.org/10.1002/hpm.931
Hanvoravongchai, P., Mounier-Jack, S., Oliveira Cruz, V., Balabanova, D., Biellik, R., Kitaw, Y., … Griffiths, U. K. (2011). Impact of measles elimination activities on immunization services and health systems: Findings from six countries. *Journal of Infectious Diseases*, *204*(SUPPL. 1). https://doi.org/10.1093/infdis/jir091
Hare, B. O. (2014). Weak health systems and Ebola. *The Lancet Global Health*, *3*(2), e71–e72. https://doi.org/10.1016/S2214-109X(14)70369-9
Helleringer, S., Asuming, P. O., & Abdelwahab, J. (2016). The effect of mass vaccination campaigns against polio on the utilization of routine immunization services: A regression discontinuity design. *Vaccine*, *34*(33), 3817–3822. https://doi.org/10.1016/j.vaccine.2016.05.037
Hemat, S., Takano, T., Kizuki, M., & Mashal, T. (2009). Health-care provision factors associated with child immunization coverage in a city centre and a rural area in Kabul, Afghanistan. *Vaccine*, *27*(21), 2823–2829. https://doi.org/10.1016/j.vaccine.2009.02.097
Hirsch, G. B., Levine, R., & Miller, R. L. (2007). Using system dynamics modeling to understand the impact of social change initiatives. *American Journal of Community Psychology*, *39*(3–4), 239–253. https://doi.org/10.1007/s10464-007-9114-3
Holte, J. H., Mæstad, O., & Jani, J. V. (2012). The decision to vaccinate a child: An economic perspective from southern Malawi. *Social Science and Medicine*, *75*(2), 384–391. https://doi.org/10.1016/j.socscimed.2012.03.015
Homer, J. B., & Hirsch, G. B. (2006). System dynamics modeling for public health:

Background and opportunities. *American Journal of Public Health*, *96*(3), 452–458. https://doi.org/10.2105/AJPH.2005.062059
Homer, J., Hirsch, G., Minniti, M., & Pierson, M. (2004). Models for collaboration: How system dynamics helped a community organize cost-effective care for chronic illness. *System Dynamics Review*, *20*(3), 199–222. https://doi.org/10.1002/sdr.295
Hotchkiss, D. R., Eisele, T. P., Djibuti, M., Silvestre, E. a, & Rukhadze, N. (2006). Health system barriers to strengthening vaccine-preventable disease surveillance and response in the context of decentralization: evidence from Georgia. *BMC Public Health*, *6*, 175. https://doi.org/10.1186/1471-2458-6-175
Hu, Y., Li, Q., Chen, E., Chen, Y., & Qi, X. (2013). Determinants of childhood immunization uptake among socio-economically disadvantaged migrants in East China. *International Journal of Environmental Research and Public Health*, *10*(7), 2845–2856. https://doi.org/10.3390/ijerph10072845
Hyde, T. B., Dentz, H., Wang, S. A., Burchett, H. E., Mounier-Jack, S., Mantel, C. F., & Group, the N. V. I. I. P. L. working. (2012). The impact of new vaccine introduction on immunization and health systems: A review of the published literature. *Vaccine*, *30*(45), 6347–6358. Retrieved from http://www.embase.com/search/results?subaction=viewrecord&from=export&id=L52194961%5Cnhttp://dx.doi.org/10.1016/j.vaccine.2012.08.029%5Cnhttp://sfx.metabib.ch/sfx_locater?sid=EMBASE&issn=0264410X&id=doi:10.1016%2Fj.vaccine.2012.08.029&atitle=The+impact+of
Informal Working Group on Vaccine Demand. (2015). Developing an indicator for measuring progress for the Second Strategic Objective of the Global Vaccine Action Plan: Final report. Geneva: WHO.
Jolliffe, I. T. (2002). *Principal Component Analysis*. *Encyclopedia of Statistics in Behavioral Science* (Second, Vol. 30). New York: Springer US. Retrieved from http://onlinelibrary.wiley.com/doi/10.1002/0470013192.bsa501/full
John Snow International. (2011). *Landscape analysis synopsis: an initial investigation of the drivers of routine immunization system performance in Africa*. Arlington.
Kim, D. H. (1992). Guidelines for Drawing Causal Loop Diagrams. *The Systems Thinker*, *3*(1), 5–6.
Kruk, M. E., & Prescott, M. R. (2012). The role of health systems and policies in promoting safe delivery in low-and middle-income countries: A multilevel analysis. *American Journal of Public Health*, *102*(4), 645–650. https://doi.org/10.2105/AJPH.2011.300462
LaFond, A., Kanagat, N., Steinglass, R., Fields, R., Sequeira, J., & Mookherji, S. (2015). Drivers of routine immunization coverage improvement in Africa: Findings from district-level case studies. *Health Policy and Planning*, *30*(3), 298–308. https://doi.org/10.1093/heapol/czu011
Lahariya, C. (2015). "Health system approach" for improving immunization program performance. *Journal of Family Medicine and Primary Care*, *4*(4), 487. https://doi.org/10.4103/2249-4863.174263
Lane, D. C. (2008). The Emergence and Use of Diagramming in System Dynamics: A Critical Account. *Systems Research and Behavioral Science*, *25*, 3–23. https://doi.org/10.1002/sres.826
Larson, H. J., Jarrett, C., Eckersberger, E., Smith, D. M. D., & Paterson, P. (2014).

Understanding vaccine hesitancy around vaccines and vaccination from a global perspective: A systematic review of published literature, 2007-2012. *Vaccine*, *32*(19), 2150–2159. https://doi.org/10.1016/j.vaccine.2014.01.081

Levin, A., Ram, S., & Kaddar, M. (2002). The impact of the Global Polio Eradication Initiative on the financing of routine immunization: case studies in Bangladesh, C te d'Ivoire, and Morocco. *Bulletin of the World Health Organization*, *80*(10), 822–828.

Lim, S. S., Stein, D. B., Charrow, A., & Murray, C. J. (2008). Tracking progress towards universal childhood immunisation and the impact of global initiatives: a systematic analysis of three-dose diphtheria, tetanus, and pertussis immunisation coverage. *The Lancet*, *372*(9655), 2031–2046. https://doi.org/10.1016/S0140-6736(08)61869-3

Lopes Cardozo, B., Bilukha, O. O., Gotway Crawford, C. A., Shaikh, I., Wolfe, M. I., Gerber, M. L., & Anderson, M. (2004). Mental Health, Social Functioning, and Disability in Postwar Afghanistan. *JAMA: Journal of the American Medical Association*, *292*(5), 575–584. https://doi.org/10.1001/jama.292.5.575

Lyon, A. R., Maras, M. A., Pate, C. M., Igusa, T., & Vander Stoep, A. (2016). Modeling the Impact of School-Based Universal Depression Screening on Additional Service Capacity Needs: A System Dynamics Approach. *Administration and Policy in Mental Health and Mental Health Services Research*, *43*(2), 168–188. https://doi.org/10.1007/s10488-015-0628-y

Macintosh, J. L. B., Eden, L. M., Luthy, K. E., & Schouten, A. E. (2017). Global Immunizations: Health Promotion and Disease Prevention Worldwide. *MCN The American Journal of Maternal/Child Nursing*, 1–6. https://doi.org/10.1097/NMC.0000000000000337

Maekawa, M., Douangmala, S., Sakisaka, K., Takahashi, K., Phathammavong, O., Xeuatvongsa, a, & Kuroiwa, C. (2007). Factors affecting routine immunization coverage among children aged 12-59 months in Lao PDR after regional polio eradication in western Pacific region. *Biosci Trends.*, *1*(1), 43–51.

MathWorks. (2016). Matlab. Bern: MathWorks.

McCullagh, P., & Nelder, J. (1983). *Generalized Linear Models*. London: Chapman and Hall.

McGlynn, N., Wilk, P., Luginaah, I., Ryan, B. L., & Thind, A. (2015). Increased use of recommended maternal health care as a determinant of immunization and appropriate care for fever and diarrhoea in Ghana: An analysis pooling three demographic and health surveys. *Health Policy and Planning*, *30*(7), 895–905. https://doi.org/10.1093/heapol/czu090

Meadows, D. (1999). *Leverage Points: Places to Intervene in a System*. Hartland. Retrieved from http://www.donellameadows.org/wp-content/userfiles/Leverage_Points.pdf

Meadows, D. (2008). *Thinking in Systems. A Primer.* (D. Wright, Ed.). White River Junction: Chelsea Green Publishing.

Ministry of Public Health, Johns Hopkins Bloomberg School of Public Health, & Indian Institute of Health Management Research. (2013). Basic package of health services balanced scorecard national report 2012-13. Retrieved from https://ije.oxfordjournals.org/content/suppl/2016/02/13/dyv362.DC1/ije-2014-10-1211-File003.pdf

Ministry of Rural Rehabilitation and Development & the Central Statistics Office (2008).

National Risk and Vulnerability Assessment 2007/8: a profile of Afghanistan. Kabul. Retrieved from catalog.ihsn.org/index.php/catalog/935/download/40450
Mofleh, J., & Ansari, J. (2014). Evaluation of measles surveillance systems in Afghanistan-2010. *Journal of Public Health and Epidemiology*, *6*(11), 407–416. https://doi.org/10.5897/JPHE2013.0643
Ministry of Public Health. (2012a). *A basic package of health services for Afghanistan - 2010/1389*. Kabul.
Ministry of Public Health. (2012b). *Comprehensive Multi- Year Plan (cMYP) For National Immunization Program (NIP) 2011-2015*. Kabul.
Mounier-Jack, S., Edengue, J. M., Lagarde, M., Baonga, S. F., & Ongolo-Zogo, P. (2016). One year of campaigns in Cameroon: effects on routine health services. *Health Policy and Planning*, *31*(9), 1225–1231. https://doi.org/10.1093/heapol/czw054
Mounier-Jack, S., Griffiths, U. K., Closser, S., Burchett, H., & Marchal, B. (2014). Measuring the health systems impact of disease control programmes: a critical reflection on the WHO building blocks framework. *BMC Public Health*, *14*(1), 278. https://doi.org/10.1186/1471-2458-14-278
Ozawa, S., Paina, L., & Qiu, M. (2016). Exploring pathways for building trust in vaccination and strengthening health system resilience. *BMC Health Services Research*, *16*(S7), 131–141. https://doi.org/10.1186/s12913-016-1867-7
Ozawa, S., & Stack, M. L. (2013). Public trust and vaccine acceptance-international perspectives, *9*(8), 1774–1778.
Paina, L., & Peters, D. H. (2012). Understanding pathways for scaling up health services through the lens of complex adaptive systems. *Health Policy and Planning*, *27*(5), 365–373. https://doi.org/10.1093/heapol/czr054
Palmer, N., Strong, L., Wali, A., & Sondorp, E. (2006). Contracting out health services in fragile states. *BMJ*, *332*, 718–21.
Pegurri, E., Fox-rushby, J. A., & Damian, W. (2005). The effects and costs of expanding the coverage of immunisation services in developing countries : a systematic literature review, *23*, 1624–1635. https://doi.org/10.1016/j.vaccine.2004.02.029
Peters, D. H., Noor, A., Singh, L. P., Kakar, F. K., & Hansen, M. (2007). Policy and practice A balanced scorecard for health services in Afghanistan. *Bulletin of the World Health Organization*, *85*(2), 146–151. https://doi.org/10.2471/BLT.06.033746
Rainey, J. J., Watkins, M., Ryman, T. K., Sandhu, P., Bo, A., & Banerjee, K. (2011). Reasons related to non-vaccination and under-vaccination of children in low and middle income countries: Findings from a systematic review of the published literature, 1999-2009. *Vaccine*, *29*(46), 8215–8221. https://doi.org/10.1016/j.vaccine.2011.08.096
Rao, K. D., Ramani, S., Hazarika, I., & George, S. (2014). When do vertical programmes strengthen health systems? A comparative assessment of disease-specific interventions in India. *Health Policy and Planning*, *29*(4), 495–505. https://doi.org/10.1093/heapol/czt035
Ravishankar, N., Gubbins, P., Cooley, R. J., Leach-kemon, K., Michaud, C. M., Jamison, D. T., … Foundation, M. G. (2007). Financing of global health : tracking development assistance for health from 1990 to 2007. *The Lancet*, *373*(9681), 2113–

2124. https://doi.org/10.1016/S0140-6736(09)60881-3
Rothman, K. J., Lash, T. L., & Greenland, S. (2008). *Modern Epidemiology* (3rd ed.). Philadelphia: Lippincott Williams & Wilkins.
Rubin, D. (1987). *Multiple imputation for survey nonresponse.* New York: Wiley.
Rwashana, A. S., Williams, D. W., & Neema, S. (2009). System dynamics approach to immunization healthcare issues in developing countries: a case study of Uganda. *Health Informatics Journal*, *15*(2), 95–107. https://doi.org/10.1177/1460458209102971
Rwashana, A., & Williams, D. (2008). System dynamics modeling in healthcare: The Ugandan immunisation system. *International Journal of Computing and ICT Research*, *1*(1), 85–98. Retrieved from http://dspace3.mak.ac.ug/xmlui/handle/10570/690
Ryman, T. K., Trakroo, A., Ekka, J. B., & Watkins, M. (2012). Contribution of Immunization Weeks toward improving coverage, access to services, and completion of recommended childhood vaccinations in Assam, India. *Vaccine*, *30*(15), 2551–2555. https://doi.org/10.1016/j.vaccine.2012.01.084
Sabri, B., Siddiqi, S., Ahmed, A., Kakar, F., & Perrot, J. (2007). Towards sustainable delivery of health services in Afghanistan: options for the future. *Bulletin of the World Health Organisation*, *85*(9), 712–719. https://doi.org/10.2471/BLT.
Sanou, A., Simboro, S., Kouyaté, B., Dugas, M., Graham, J., & Bibeau, G. (2009). Assessment of factors associated with complete immunization coverage in children aged 12-23 months: a cross-sectional study in Nouna district, Burkina Faso. *BMC International Health and Human Rights*, *9 Suppl 1*(Suppl 1), S10. https://doi.org/10.1186/1472-698X-9-S1-S10
Save the Children. (2012). *State of the World's Mothers, 2011. Champions for Children. Save the Children*. Fairfield. Retrieved from http://www.savethechildren.org/atf/cf/%7B9def2ebe-10ae-432c-9bd0-df91d2eba74a%7D/SOWM2011_FULL_REPORT.PDF
Save the Children. (2013). *State of the World's Mothers. Surviving the First Day*. Fairfield.
Save the Children. (2015). *State of the world's mothers 2015: The Urban Disadvantage*. Fairfield. Retrieved from http://www.savethechildren.org/atf/cf/%7B9def2ebe-10ae-432c-9bd0-df91d2eba74a%7D/SOWM_2015.PDF
Semwanga, A. R., Nakubulwa, S., & Adam, T. (2016). Applying a system dynamics modelling approach to explore policy options for improving neonatal health in Uganda. *Health Research Policy and Systems*, *14*(1), 35. https://doi.org/10.1186/s12961-016-0101-8
Shea, B., Andersson, N., & Henry, D. (2009). Increasing the demand for childhood vaccination in developing countries: a systematic review. *BMC International Health and Human Rights*. https://doi.org/10.1186/1472-698X-9-S1-S5
Shearer, S., Walker, D., Risko, N., & Levine Orin. (2012). The impact of new vaccine introduction on the coverage of exisitng vaccines: a cross-national, multivariable analysis. *Vaccine*, *30*, 7582–7587.
Shen, A. K., Fields, R., & McQuestion, M. (2014). The future of routine immunization in the developing world: challenges and opportunities. *Global Health, Science and Practice*, *2*(4), 381–94. https://doi.org/10.9745/GHSP-D-14-00137

Sodha, S. V., & Dietz, V. (2015). Strengthening routine immunization systems to improve global vaccination coverage. *British Medical Bulletin*, *113*(1), 5–14. https://doi.org/10.1093/bmb/ldv001

Stata Corp LLC. (2011). Stata 12 I/C. College Station.

Steinglass, R. (2013). Routine immunization: an essential but wobbly platform, *1*(3), 295–301.

Steinhardt, L. C., Waters, H., Rao, K. D., Naeem, A. J., Hansen, P., & Peters, D. H. (2009). The effect of wealth status on care seeking and health expenditures in Afghanistan. *Health Policy and Planning*, *24*(1), 1–17. https://doi.org/10.1093/heapol/czn043

Strong, L. (2003). Health Policy in Afghanistan : two years of rapid change from 2001 to 2003 Health Policy in Afghanistan : two years of rapid change.

Suarez-Castaneda, E., Burnett, E., Elas, M., Baltrons, R., Pezzoli, L., Flannery, B., … Danovaro-holliday, M. C. (2015). Catching-up with pentavalent vaccine : Exploring reasons behind lower rotavirus vaccine coverage in El Salvador ☆. *Vaccine*, *33*(48), 6865–6870. https://doi.org/10.1016/j.vaccine.2015.07.092

Tao, W., Petzold, M., & Forsberg, B. C. (2013). Routine vaccination coverage in low-and middle-income countries: Further arguments for accelerating support to child vaccination services. *Global Health Action*, *6*(1), 1–8. https://doi.org/10.3402/gha.v6i0.20343

Tapia-Conyer, R., Betancourt-Cravioto, M., Saucedo-Martínez, R., Motta-Murguía, L., & Gallardo-Rincón, H. (2013). Strengthening vaccination policies in Latin America: An evidence-based approach. *Vaccine*, *31*(37), 3826–3833. https://doi.org/10.1016/j.vaccine.2012.12.062

Tappis, H., Koblinsky, M., Doocy, S., Warren, N., & Peters, D. H. (2016). Bypassing Primary Care Facilities for Childbirth: Findings from a Multilevel Analysis of Skilled Birth Attendance Determinants in Afghanistan. *Journal of Midwifery and Women's Health*, *61*(2), 185–195. https://doi.org/10.1111/jmwh.12359

The World Bank, & the Islamic Republic of Afghanistan Ministry of Economy (2016). *Afghanistan: Provincial briefs*. Washington, DC. Retrieved from http://pubdocs.worldbank.org/en/298721480548197402/AFGHANISTAN-PROVINCIAL-BRIEFS-ENG-20-11-16.pdf

Trani, J. F., Bakhshi, P., Noor, A. A., Lopez, D., & Mashkoor, A. (2010). Poverty, vulnerability, and provision of healthcare in Afghanistan. *Social Science and Medicine*, *70*(11), 1745–1755. https://doi.org/10.1016/j.socscimed.2010.02.007

Travis, P., Bennett, S., Haines, P. A., Pang, T., Bhutta, P. Z., Hyder, A. A., … Evans, T. (2004). Overcoming health-systems constraints to achieve the Millennium Development Goals. *Lancet*, *364*(9437), 900–906. https://doi.org/10.1016/S0140-6736(04)16987-0

Turner, a G., Magnani, R. J., & Shuaib, M. (1996). Not quite as quick but much cleaner alternative to the expanded programme on immunization cluster survey design. *International Journal of Epidemiology*, *25*(1), 198–203.

UNICEF. (2016a). *State of the world's children 2016: a fair chance for every child*. New York. Retrieved from https://www.unicef.org/publications/index_91711.html

UNICEF. (2016b). Unicef: Afghanistan. Retrieved February 23, 2017, from https://www.unicef.org/afghanistan/media_9898.htm

UNICEF. (2017). Child survival: Immunization. Retrieved February 28, 2017, from https://www.unicefusa.org/mission/survival/immunization

van Olmen, J., Marchal, B., Van Damme, W., Kegels, G., & Hill, P. S. (2012). Health systems frameworks in their political context: framing divergent agendas. *BMC Public Health*, *12*(1), 774. https://doi.org/10.1186/1471-2458-12-774

Varghese, J., Kutty, V., Paina, L., & Adam, T. (2014). Advancing the application of systems thinking in health: understanding the growing complexity governing immunization services in Kerala, India. *Health Research Policy and Systems*, *12*(1), 47. https://doi.org/10.1186/1478-4505-12-47

Ventana Systems. (2015). Vensim PLE. Harvard. Retrieved from https://vensim.com/

Vickers, a J. (2001). The use of percentage change from baseline as an outcome in a controlled trial is statistically inefficient: a simulation study. *BMC Medical Research Methodology*, *1*, 6. https://doi.org/10.1186/1471-2288-1-6

Wado, Y. D. ibaba, Afework, M. F. antahun, & Hindin, M. J. (2014). Childhood vaccination in rural southwestern Ethiopia: the nexus with demographic factors and women's autonomy. *The Pan African Medical Journal*, *17*(Supp 1), 9. https://doi.org/10.11694/pamj.supp.2014.17.1.3135

Wang, S. A., Hyde, T. B., Mounier-jack, S., Brenzel, L., Favin, M., Gordon, W. S., … Durrheim, D. (2012). New vaccine introductions : Assessing the impact and the opportunities for immunization and health systems strengthening.

Wang, S. A., Hyde, T. B., Mounier-Jack, S., Brenzel, L., Favin, M., Gordon, W. S., … Durrheim, D. (2013). New vaccine introduction: assessing the impact and the opportunities for immunization and health systems strengthening. *Vaccine*, *31*. https://doi.org/10.1016/j.vaccine.2012.10.116

WHO. (2000). *World Health Report 2000. Health Systems: Improving Perfomance*. *World Health Organization* (Vol. 78). Geneva. https://doi.org/10.1146/annurev.ecolsys.35.021103.105711

WHO. (2007). *Everybody's business: strengthening health systems to improve health outcomes: WHO's framework for action.* Geneva. Retrieved from http://www.who.int/healthsystems/strategy/everybodys_business.pdf

WHO. (2011a). *Afghanistan Effective Vaccine Management assessment, 24 July - 11 August 2011*. Geneva.

WHO. (2011b). *Global Vaccine Action Plan 2011-2020*. Geneva.

WHO. (2013). *Country Cooperation Strategy for WHO and Oman 2010–2015pdf*. https://doi.org/WHO-EM/ARD/037/E

WHO. (2015). MDG 4: reduce child mortality. Retrieved February 28, 2017, from http://www.who.int/topics/millennium_development_goals/child_mortality/en/

WHO-Maximizing Positive Synergies Collaborative Group. (2009). An assessment of interactions between global health initiatives and country health systems. *The Lancet*, *373*(9681), 2137–2169. https://doi.org/10.1016/S0140-6736(09)60919-3

WHO; Alliance for Health Policy and Systems Research. (2009). *Systems thinking for health systems strengthening*. Geneva.

WHO, & Strategic Advisory Group of Experts on Immunization. (2015). *2015 Assessment Report of the Global Vaccine Action Plan*. Geneva. Retrieved from http://www.who.int/immunization/global_vaccine_action_plan/SAGE_GVAP_Assessment_Report_2015_EN.pdf?ua=1

Intended to be blank.

Appendix I. Description of variables used for creating mean index-based scores for immunization readiness variables

Table 18. List of variables used to construct mean, index-based scores for immunization system readiness covariates in Chapter 3

	DESCRIPTION	ANSWER STRUCTURE
Cold chain		
f7_hfprovides_epi	Does this facility provide EPI services?	y/n
f7_vaxfridge_present	Is there a vaccine refrigerator?	
f7_vaxfridgeworks	Is the vaccine refrigerator working?	
f7_vaxfridge_functpower	Is there a functioning power source for the vaccine refrigerator?	
f7_vaxthermworks	Is the main vaccine thermometer present and working?	present, working; present, not working; not present
f7_templog	Is a temperature log kept?	at least twice a day for past 30 days; less than twice a day readings; no vaccine log kept
f7_coldboxworks	Is the cold box present and working?	present, working; present, not working; not present
f7_vaxcarrierworks	Is the vaccine carrier present and working?	
f7_vaxthermworks	Is there a thermometer?	present, working; broken or missing
Management		
f7_imcichart_present	Ask to see the protocols/guidelines and check to see which of the following are present.	present; not present
f7_immunizsched_present		present; not present
Precautions		
f7_precaution_safetybox	Is there evidence that safety boxes or closed containers are being used properly for disposal of used sharps?	Yes, and satisfactory; yes, but not satisfactory; no
f7_precaution_syringes	Is there evidence that syringes are being disposed of WITHOUT being recapped?	
f7_precaution_chlorine	Is there 0.5% chlorine solution for soaking syringes and other items?	
f7_precaution_decontam	Are there posted procedures for decontamination procedure steps?	
f7_precaution_h20soap	Is a basin with a water source and soap available in this room?	
Training, F6		
f6_trx12mo_cIMCI	Have you received any refresher training since your basic CHW training?	No training since basic CHW training; any training since basic CHW training; related training (but not vax-specific) since basic CHW training; vax-specific since CHW basic training
f6_trx12mo_tb		
f6_trx12mo_malaria		
f6_trx12mo_FPmethods		
f6_trx12mo_vax		
f6_trx12mo_nutrition		
f6_trx12mo_hygiene		
f6_trx12mo_childhood		
f6_trx12mo_none		
f6_trx12mo_notlisted		

Training, F5		
f5_trx12mo_IMCI f5_trx12mo_MNH f5_trx12mo_precautions f5_trx12mo_CHW f5_trx12mo_HIVAIDS f5_trx12mo_tb f5_trx12mo_malaria f5_trx12mo_FPmethods f5_trx12mo_nutrition f5_trx12mo_mental f5_trx12mo_disabilities	Have you received in-service training in the past 12 months?	in the last 12mo; no, or more than 12mo ago or never
f5_trx12mo_vaxdichot	Have you received vaccine-specific training in the past 12 months?	yes/no
f5_trx12mo_vaxcat	Have you received vaccine-specific training in the past 12 months?	no training in past 12mo; any training in past 12mo; related training (but not vax-specific; IMCI, MNH, precautions, CHW) in past 12mo; vax-specific in past 12mo
Health workers		
vaccinators nurses community midwives physicians obgyns midlevels	Number who have worked in the facility during the past month (male/female)	counts
Laboratory		
lab_tbsmears lab_malariasmears lab_gram lab_rapidmalaria lab_liverfunction lab_hepB	For health facilities that report a laboratory present, are you able to do these tests?	Able to do this test today; able to do in the past 6 months but not today; cannot do this test
Vaccine stock		
BCG BCG, expired OPV OPV, expired TT	Has the item been continuously available for the past 30 days (according to the stock control card or drug registry)	Continuously available (yes/no); If yes, are expired items present? (yes; no, drug stocks are current; no expiry date visible; drug is not present)

TT, expired
PENTA
PENTA, expired
Measles
Measles, expired

Appendix II. Wealth status scoring coefficients

Table 19. Components used for creating household wealth quintiles and their scoring coefficients from the 2012-13 Afghanistan Health Survey data

S.No.	Variable	Variable name	Scoring coefficients
1	Main income source - Argriculture or Rearing Animals	incagr	-0.1547
2	Main income source - Service/Salaried	incserv	0.1485
3	Main income source - Business/trading	incbus	0.117
4	Main income source - Remittance	incremit	0.0277
5	Main income source - Seasonal worker	incseas	-0.0248
6	Main income source - Daily wages	inclabor	-0.0348
7	Main income source - Other	incother	0.0066
8	Main source lighting - Electrical Mains	litmains	0.2059
9	Main source lighting - Generator	litgen	0.0652
10	Main source lighting - Batteries	litbatt	-0.1008
11	Main source lighting - Gas Lamp	litgas	-0.0095
12	Main source lighting - Oil or Kerosene Lamp	litker	-0.1498
13	Main source lighting - Other	litother	-0.0259
14	No source of lighting	litnone	-0.0033
15	Water in residence including open well	watres	0.2277
16	Public tap/handpump	watpublic	-0.0632
17	Well (open/covered) outside residence	watwell	-0.0393
18	Surface water including protected spring	watsurface	-0.1865
19	Tanker/truck	wattank	0.0257
20	Other water source	watother	-0.0014
21	Main source fuel - Gas, Electricity or Kerosine	fuelgaselect	0.2828
22	Main source fuel - Firewood	fuelfire	-0.0461
23	Main source fuel - Crop residues or bushes	fuelcrop	-0.1433
24	Main source fuel - Charcoal	fuelcoal	-0.0144
25	Main source fuel - Dung	fueldung	-0.087
26	Main source fuel - Other including trash	fuelother	-0.016
27	Toilet - flush private	tlprivflush	0.2462
28	Toilet - flush shared	tlshareflush	0.0872
29	Toilet - traditional pit	tlpit	-0.0576
30	Toilet - Open backed	tlfield	-0.1182
31	Toilet - Field or outside house	tlopenback	-0.0486
32	Assets - Fridge	assfridge	0.2643
33	Assets - Stove/Gas	assgasstov	0.2134
34	Assets - Sewing machine	asssew	0.1102
35	Assets - Iron	assiron	0.1933
36	Assets - Radio	assradio	0.0955
37	Assets - TV	asstv	0.2552
38	Assets - DVD player	assdvd	0.1696
39	Assets - Satellite phone	asssatphone	0.0443
40	Assets - Cell phone	asscell	0.1309
41	Assets - Bike	assbike	0.0858
42	Assets - Motorcycle	assmot	0.0745
43	Assets - Car	asscar	0.1758
44	Assets - Tractor	asstract	0.001
45	Assets - Thresher	assthresher	-0.0016
46	Roofing - wood	rofwood	-0.0297
47	Roofing - mud	rofmud	-0.1179
48	Roofing - metal, brick, concrete	rof_metalbrickconcrete	0.2199
49	Roofing - other including plastic sheeting and asphalt tiles	rofother	0.1019
50	Floor - mud	flormud	-0.2857
51	Floor - concrete	florconcrete	0.2677
52	Floor - wood, tile, other	florother	0.0934

Source: Afghanistan Health Survey 2012 Final Report. **(Afghan MoPH et al., 2012)**.

Intended to be blank.

Curriculum Vitae

HOLLY SCHUH

Contact +1 507 319 3498 ◆ hschuh1@jhu.edu

414 Water St, Baltimore, MD 21202

Research interests systems dynamics | monitoring and evaluation for health systems strengthening | health service delivery in fragile states | routine immunization system performance in LMIC | health equity | poverty & health | aging and protracted displacement | measuring accountability and governance

Education

Doctor of Philosophy (candidate): International Health
Johns Hopkins Bloomberg School of Public Health, Baltimore, MD (2011-2017)
Program: Health Systems

Doctoral thesis: *Measuring a subsystem-system relationship and tradeoffs in Afghanistan: a country case study examining the role of immunization in health system performance*

Master of Public Health: Global Health
Loma Linda University, Loma Linda, CA (2008-2011)
Emphasis**:** Epidemiology and Public Health Research

Anne Lee Health Administration Resource Development Award (2011)
MJDM Goh Global Partner Award (2011)
Serrao Health Policy & Management Practice Scholarship (2010)
Hulda Crooks Scholarship Award (2010)
Wil Alexander Whole-Person Care Award (2010)
Becky Bushman Memorial SPH Scholarship (2010)
Selma Andrews Award (2009 & 2010)

Bachelor of Arts: Visual Arts: Business Concentration
Saint Mary's University, Winona, MN (2004-2008)
Minors: Music and Biology

Saint Tomas Academic Award (2004-2008)
Mayo Innovations Scholar in Biology (2007)
Saint Luke Art and Design Award (2004)
Saint Cecilia Music Award (2004)

Work experience

World Health Organization (WHO), HQ **Geneva, Switzerland**
Consultant – Department of Immunization, Vaccines, and Biologicals
April 2015 – Jan 2016

- Coordinated the development of monitoring and evaluation methods for vaccine demand, value, and hesitancy component of the Global Vaccine Action Plan (GVAP)
- Development of the Behavioral Sciences Action Plan for the IVB Department that specifies how the department will integrate new disciplines into its infrastructure and its strategy for engagement with partners (new

disciplines focused on actor- and non-actor behavior, includes system behavior)

VIEW Scholar, intern – Department of Immunization, Vaccines, and Biologicals
Sept 2014 – Dec 2014

- Coordination of the development of monitoring and evaluation methods for vaccine demand, value, and hesitancy component of the Global Vaccine Action Plan (GVAP)

United Nations Children's Fund (UNICEF), HQ **New York City, USA**
Consultant – Global Immunization Program
Jan 2015

- Coordinated the informal Working Group on Vaccine Demand (iWGVD) for UNICEF during a three-day meeting on the vaccine demand, value, and hesitancy component of the Global Vaccine Action Plan (GVAP)
- Developed a final meeting summary and report
- Reported the output from a rapid literature review on vaccine demand terminology and a conceptual framework for exploring vaccine demand as a construct

Johns Hopkins Bloomberg School of Public Health (JHSPH) **Baltimore, USA**
Graduate Researcher – Department of International Health
June 2013 – Sept 2013

- Coordinated authors for review on Bangladesh health system
- Co-authored two reports on the Bangladesh health system organization and monitoring system

Graduate Researcher – Department of International Health
June 2012 – May 2013
Technical Manager, Johns Hopkins University Kabul Afghanistan Office

- Responsible for design and implementation of data quality control measures for a national household survey
- Mentored local staff in the areas of basic epidemiology and public health research, use of Stata statistical packages, data monitoring and quality control, and English (ASL)
- Assisted in data analysis and publication development

Loma Linda University (LLU) **Loma Linda, USA**
Instructor – School of Public Health, Global Health Department
July 2011 – Present

- Current teaching responsibilities on hold (away on sponsorship leave pursuing PhD)
- Participating in Global Lens working group

Research Technician – Institute for Community Partnerships
March 2011 – July 2011

- Responsible for oversight of research at Institute
- Assisted in proposal writing

Project Coordinator –Department of Neurology, LLU Medical Center (LLUMC)
May 2010 – July 2011

- Lead as Project Coordinator for Project RECAP (Research Exploring Cognitive Aging Perceptions)
- Wrote proposal and created budget for Project RECAP – received seed grant funding for project
- Assisted in writing for publication of findings and grant proposals in Department of Neurology

Graduate Research Assistant – Center for Health Research, School of Public Health
Jan 2010 – July 2011

- Assisted director with junior faculty mentoring groups and school-wide faculty-student research meetings
- Managed Institutional Review Board correspondence and protocol
- Assisted in preparation and writing of grant proposals
- Assisted in data collection and statistical analysis for report to Council on Education for Public Health

Graduate Research Assistant – Department of Global Health
Feb 2009 – July 2011

- Assisted in class and curriculum management
- Lectured as teaching assistant in two courses
- Conducted benchmarking for revision of department standards

Qualitative Research Consultant –Community Health Development at LLUMC
July 2010 – Jan 2011

- Coordinated student research team for LLUMC's quality of care Community Benefits Assessment
- Served as liaison and consultant for San Antonio Community Hospital for its community assessment
- Summarized findings and editor for final report

Graduate Research Assistant – Center for Health Disparities and Molecular Medicine
Feb 2009 – Nov 2010

- Authored and published the monthly diversity newsletters
- Conducted background research for proposals and projects
- Lead in writing publications of findings of *Project Access*

Latino Health Collaborative **San Bernardino, USA**
Research Assistant
Feb 2009 – Dec 2009

- Conducted focus groups, informant interviews, and surveys using CBPR methods
- Managed and assisted in completion of deliverables such as monthly and final reports due to the San Bernardino County Department of Behavioral Health
- Supported design and creation of research and marketing tools

Publications **Schuh HB**, Merritt M, Igusa T, Lee B, Peters DH (2017). Title. *International Journal for Health Governance*. Submitted March 2017. Currently under review.

Hickler B, MacDonald NE, Senouci K, **Schuh HB** (2017). Efforts to monitor global progress on individual and community demand for immunization: Development of definitions and indicators for the Global Vaccine Action Plan Strategic Objective 2. *Vaccine*. Under review.

Schuh HB, Chang K, MacDonald NE, Nan Li G, Hickler B, Senouci K, the informal Working Group on Vaccine Demand (iWGVD) (2017). Definitions and connotations of 'Vaccine Demand': a qualitative analysis of terminology in the vaccine literature. *Vaccine.* Under review.

Engineer CY, Dale E, Agarwal A, Agarwal A, Alonge O, Edward A, Gupta S, **Schuh HB**, Burnham G, Peters DH (2016). Effectiveness of a pay-for-performance intervention to improve maternal and child health services in Afghanistan: a cluster-randomized trial. *International Journal of Epidemiology, 45(2):* 451-9. doi: 10.1093/ije/dyv362.

Roberts LR, **Schuh H**, Sherzai D, Belliard JC, Montgomery SB (2015). Exploring experiences and perceptions of aging and cognitive decline across diverse racial and ethnic groups. *Gerontology and Geriatric Medicine Jan-Dec(1).* doi: 10.1177/2333721415596101.

Presentations & reports

Exploring feedback and effects of immunization systems interventions on Afghanistan's health system using system dynamics modeling. Oral presentation, Health Systems Research fourth biannual symposium. Vancouver, BC. (November 2016)

Behavioral Sciences Action Plan for the Department on Immunisation, Vaccines, and Biologicals at the World Health Organization in Geneva, Switzerland. A work-plan for integrating social and behavioral science expertise into the WHO immunization-focused infrastructure, system, and activities. (January 2016)

Developing an indicator for measuring progress for the Second Strategic Objective (SO2) of the Global Vaccine Action Plan: "Individuals and communities understand the value of vaccines and demand immunization as both their right and responsibility. Final report by the information Working Group on Vaccine Demand (iWGVD) established by the World Health Organization and UNICEF to the Strategic Advisory Group of Experts on Immunisation (SAGE). (September 2015)

Impact evaluation of the results based financing intervention in Afghanistan, final report (June 2013). Organizations represented include: the Johns Hopkins Bloomberg School of Public Health (JHSPH), the Indian Institute of Health Management and Research (IIHMR) and Ministry of Public Health (MoPH) of the Islamic Republic of Afghanistan.

Afghanistan health survey (AHS) 2012, final report (June 2013). Organizations represented include: the Johns Hopkins Bloomberg School of Public Health (JHSPH), the Indian Institute of Health Management and Research (IIHMR), and Ministry of Public Health (MoPH) of the Islamic Republic of Afghanistan.

Aging in displacement: assessing health status of displaced older adults in the Republic of Georgia, report (April 2012). A study conducted by the Johns Hopkins Bloomberg School of Public Health and the Institute for Policy Studies.

Schuh, H., Manning, B., Bada, A., Jara, E., Montgomery, S. (2010). Ensuring the competency of future public health professionals: Understanding the balance between the human factor with the practical application of skills using Photovoice. Poster presentation at 138th APHA annual meeting, Denver, CO.

Adam, A. & Schuh, H. (2010). Integrating community resources to enhance management of dementia using GIS. Poster presentation at 138th APHA annual meeting, Denver, CO.

Adam, A. & Schuh, H. (2010). Effectively building social capital: Social networking for public health campaigns. Oral presentation at 138th APHA annual meeting, Denver, CO.

McField, E., Montgomery, S., Belliard, J.C., James, S., Schubert, C., Schuh, H. (2010). Promoting equity in access to mental health services: Exploring cultural attitudes among Latinos. Oral presentation at 138th APHA annual meeting, Denver, CO.

Schuh, H., Mundy, T., Shittu, A., Gaede, D.P, Iheasirim, S., Montgomery, S. (2010). Understanding community emergency preparedness: Exploring networks and modes of communication in an underserved ethnic minority community. Oral presentation at 138th APHA annual meeting, Denver, CO.

Schuh, H., McField, E., Belliard, J.C. (2010). Value of community based participatory research in a Vietnamese community: Accessing the mental health care system in San Bernardino community. Oral presentation at 138th APHA annual meeting, Denver, CO.

McField, E., Cheema, R., Belliard, J.C., Schuh, H. (2009). Approaches to increasing access and quality of mental health services for African Americans, Asian Americans, and Latinos. Poster presentation at 137th APHA annual meeting, Philadelphia, PA.

Desai, A., Lee, B., Schuh, H., Koch, S., Serrao, S. (2009). Medical bankruptcy: A weight on medicine's shoulders. Poster presentation at 2009 American Healthcare Congress Summit in Ontario, CA.

Field work

National household survey, Afghanistan — June 2012 – June 2013
Results-based Financing project, Afghanistan — June 2012 – June 2013
Project RECAP (Research Exploring Cognitive Aging Perceptions) Mar 2010 – July 2011
Complementary Alternative Medicine Use among Cancer Patients Mar 2010 – June 2010
Project ACCESS: Exploring access to mental health services in San Bernardino County Jan 2009 – Dec 2009
Quality Assessment Tool – Department of Psychology at LLUMC Sept 2009 – Dec 2009
Assessment of Women's Health and Traditional Stove Use in Peru Sept 2008 – July 2010
Creating Infrastructure for Emergency Preparedness in Westside San Bernardino through community engagement Sept 2008 – June 2009

Grant writing

Linking lifetimes in displacement: a pilot study of intergenerational exchange in the Republic of Georgia (PRM-PRP12-CA-04022012 – Center for Refugee and Disaster Response – Spring 2012.

NIMHD Exploratory Centers of Excellence (P20) Grant (RFA-MD-11-002) – Center for Health Disparities Research at LLU – Spring 2011. *Funded.*

Childhood Obesity Research Demonstration (RFA-DP-11-007) – Centers for Disease Control and Prevention – Office of Community Health Development at LLU – Spring 2011.

BlueVillage Initiative GRASP proposal (2010). Seed funding through Loma Linda University.

iCARE grant: Recovery Act Limited Competition: Building Sustainable Community-Linked Infrastructure to Enable Health Science Research (RC4) (2009). Federal (NIH) funding.

Save-the-Water Mission Proposal for Namikasi Secondary School in Blantyre, Malawi (2009). Funding organization: Pacific MBA Global Development Fund. *Funded.*

Save-Life-Fund Mission Proposal for Gimbie Adventist Hospital in Gimbie, Ethiopia (2009). Funding organization: Pacific MBA Global Development Fund. *Funded.*

Crosswalk Kindergarten Mission Proposal for the Learning Village in Kalaala, Ethiopia (2009). Funding organization: Pacific MBA Global Development Fund. *Funded.*

Girls Residence Construction for Namikasi Secondary School in Blantyre, Malawai (2009). Funding organization: Pacific MBA Global Development Fund. *Funded.*

Teaching experience

Teaching Assistant, PH.221.652: Health financing in LMIC — Winter 2013
Johns Hopkins Bloomberg School of Public Health

- Assisted in management of assignments and online forum
- Graded and managed assignments
- Helped to manage the classroom and answered students' questions

Private Instructor, Piano Instrument, Ear Training, and Music Theory
Summer 2002 – Summer 2011
Minnesota and Southern California's Inland Empire

- Designs theory and composition curriculum practicing creative pedagogy
- Instructs beginning through advanced music theory and application

Co-lecturer, STAT515: Grant and Proposal Writing — Winter 2011
School of Public Health, Loma Linda University

- Assisted in design of teaching tools and content selection for course
- Lectured on basic principles of grant writing and assist in lab exercises

Teaching Assistant, GLBH524: Cultural Competence and Health Disparities
Winter 2011
School of Public Health, Loma Linda University

- Assisted with online management of assignments, grades, and threads
- Graded assignments
- Lead lab through lecturing and facilitating student activities

Mentor for student research group, Research Methods Summer 2010 – Winter 2011
School of Public Health, Loma Linda University

- Lead small work groups presenting data collection tools used in qualitative and quantitative research
- Instructed small work groups in data analysis
- Assessed quality of student work providing constructive feedback

Teaching Assistant, Health Policy and Management Summer 2009 – Spring 2010
Department of Health Policy and Leadership, School of Public Health, Loma Linda University

- Served as student liaison to professors for the following classes: HADM 509: Principles of Health Policy and Management; HADM555: Healthcare Delivery Systems; and, HADM534: Healthcare Law
- Assisted in grading and management of assignments
- Wrote proposals for Ethiopian projects to acquire small seed grants for student- and FBO-led projects

In-Field Instructor, Nutrition Classes in Ccotos, Peru Summer 2009
Department of Global Health, School of Public Health, Loma Linda University

- Designed teaching curriculum and selected culturally-appropriate content
- Assisted in lecturing at workshops

In-Field Instructor, Emergency Preparedness and Capacity Building
Winter – Spring 2009
Department of Global Health, School of Public Health, Loma Linda University

- Designed teaching curriculum and selected culturally-appropriate content
- Assisted in lecturing at workshops

Service

Demand generation working group, Gavi Alliance for vaccines, member (Sept-Dec 2016)
the informal Working Group on Vaccine Demand (iWGVD) to the Strategic Advisory (Jan-Sept 2016)
Group of Experts on Immunisation (SAGE), member (April-Sept 2016)
Volunteer server and prep, Beans & Bread kitchen, Baltimore MD, (2013)
English / Epidemiology instructor, Johns Hopkins U. Office, Kabul Afghanistan (2012)
ANON Foundation, Philanthropy and Marketing (2010)
SAKE (Small Acts of Kindness Evangelism) (2008-2010)
Vacation Bible School at Campus Hill Church in Loma Linda, CA (Summer 2009)
Constituent for MN Conference of Seventh-day Adventists (2008-2009)
Women's Leadership and Service Institute (2006-2008)
Church pianist at Rochester Seventh-day Adventist church (2004-2008)
Deaconess at Rochester Seventh-day Adventist church in Rochester, MN (2002-2008)
Medical Outreach with Mayo Clinic and Maranatha, India (2006)

Professional Health Systems Global, member

associations	American Public Health Association, member Global Health Council, member Minnesota Conference of Seventh-day Adventists, former constituent
Other honors & awards	Vaccine Internship Experience at the World Health Organization (VIEW) Scholar (September-December 2014). American Health Care Congress – Southern California Health Care Summit Best student poster and policy review (2009). *Medical Bankruptcy: a policy review.* Mayo Clinic, Rochester, MN – Mayo Scholars Program Mayo Scholar (2008 -2009) – Selected to collaborate on research/business plan for studies submitted by researchers through the Mayo Clinic Office of Intellectual Property. VSA Arts, Smithsonian Institute, and Volkswagen of America – 2007 *Driven* Exhibition Award of Excellence (2007) – Personal art works (original paintings) displayed at the Smithsonian Institute S. Dillon Ripley Center and the Kennedy Center of Performing Arts located in Washington, DC. Toured the USA through 2010.
Software skills	*Quantitative and Spatial Analysis:* Stata, SAS, SPSS, EpiInfo, Vensim PLE, ArcGIS *Coding, Publishing, Reference management:* Mendeley, EndNote, Microsoft Office Tools *Music and Image Processing:* Adobe Photoshop, Finale Music Notation, MIDI applications
Languages	English (native); français (intermediate: speaking: b2; listening: b1; reading/writing: b2); دری (basic)
Avocations & interests	creative pedagogy | music theory & composition | fine arts | ethics | pilates and fitness culinary arts & nutrition | economics | linguistics | travel | demography | Christian ministry
References	Available upon request